THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XXXIII MARCH 1911 NUMBER 2

ON THE EMISSIVE POWER OF WEDGE-SHAPED CAVITIES AND THEIR USE IN TEMPERATURE MEASUREMENTS

By C. E. MENDENHALL

In practically all investigations of the radiating properties of metallic and other surfaces, the least accurate and most difficult part has been the determination of the true temperature of the radiating surface. This is true even within the range of accurate thermo-electric measurements, but more especially above this range, say from 1700° C. up, where lie the working temperatures of the various incandescent lamps, carbon, tantalum, tungsten, and osmium. The only methods so far found available for use in this extreme range are the radiation methods, total or partial, based respectively upon the law of Stefan-Boltzman or the equation of Wien. As ordinarily applied to a radiating surface, however, these give not the *true* but the so-called black-body temperature, i.e., the temperature of the radiantly equivalent black body.

The device to be described promises to be of some value because it enables one with a calibrated optical pyrometer to determine the *true* temperature of a radiating surface. It is, of course, nothing but a special scheme for obtaining the Kirchhoff black-body conditions—a black body being defined, as usual, by the conditions, a=absorptive power=1; it will have, of course, the maximum possible emissive power at any temperature. The

special scheme referred to is shown in Fig. 1, where F is a flat conducting ribbon, heated by a longitudinal electric current as shown, and folded on a line parallel to the length so that the resulting cross-section perpendicular to the current-flow is a very narrow V—say with about 10° angular opening. If the ribbon is of uniform thickness and width it will be raised to a uniform temperature by a given current, except near the ends. The inside of the V might be then expected to be a close approximation to a black body, or total radiator, since it has but a small opening and uniformly heated walls, and if this were so, observations on it with an optical pyrometer would give the *true* and not the "black-body" temperature of its inside walls. The *outside* of the V will give radiation characteristic of the material of the ribbon, and could be used to study this radiation; but before we can draw conclusions as to the temperature of the *outside* surface we must evidently consider two questions:

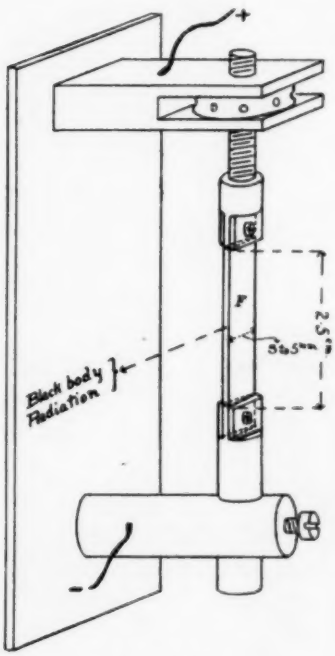


FIG. 1

1. How closely does the radiation from the inside of the V approximate that of a black body at the temperature of the *inside* walls?

2. How much real temperature difference is there between the inside and outside surface of the wall of the V?

The most convenient way of answering the first question follows the method used by Ch. Féry[1] in discussing the absorbing power of cones.

If AOB (Fig. 2) represents a section of the V perpendicular to its length, the walls being supposed plane and specularly reflecting,

[1] *Comptes Rendus*, **148**, 777, 1909.

then a ray entering in, or nearly in, the plane of the paper will be reversed in direction and emerge after $n=\frac{180}{a}$ reflections. If the reflecting power of the surface is r, the effective reflecting power of the cavity will be r^n, and since there is no transmission the effective absorbing power will be $A=1-r^n$. Thus if $r=0.7$ (about that for a perfect surface of platinum) and $a=10°$, $r^n=0.0016$, and the emissive power $E=Ae=0.998e$, where e=emissive power of a total radiator. This departure from perfect emissivity ($E=e$) would correspond for $\lambda=0.658$ to a temperature difference of less than 0°.5 at 1600° C. To this degree of accuracy, then,

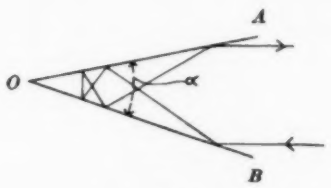


FIG. 2

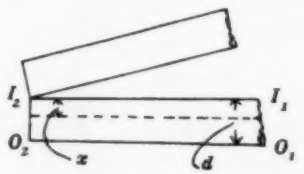


FIG. 3

optical pyrometer observations in the V aperture would give, under these conditions, the true temperature of the inside walls. If the inside surface of the wedge is matt instead of specularly reflecting, the previous conditions will not hold, but an estimate of the mean absorbing power may be obtained by considering the angle subtended by the opening at the middle point of the side, so that if the actual absorbing power of the surface is $A=0.8$ the average effective absorbing power is $A'=0.3+(0.9\times0.2\times0.8)+(0.9\times0.2)^2\times0.8+=0.97$. If $A=0.95$, $A'=0.995$. It is evident that, in order to obtain a given *effective* absorbing power with a matt surface, it must have a very much higher absorbing power (lower reflecting power) than is necessary with a specularly reflecting surface.[1]

The second question may be answered by the following consid-

[1] Féry (*op. cit.*), in computing the effective absorbing power of his cones, treats them as specularly reflecting though they are lamp-blacked. This assumption can hardly be correct, and must lead to too high a computed absorbing power.

erations. Let $I_1\ I_2\ O_1\ O_2$ (Fig. 3) represent a cross-section perpendicular to the edge of one wall of the wedge.

Assume that the heat energy is produced uniformly over the cross-section, and that none of it can escape from the inside ($I_1 I_2$), but must pass by conduction to the outside ($O_1 O_2$); these assumptions will at least give an upper limit to the temperature-difference between I and O. If t represents the temperature over any plane distant x from the inside, k the thermal conductivity at this temperature, w the calories converted into heat per unit length and unit cross-section of filament, then the following equation must hold for the heat passing across unit lateral area of the plane "x":

$$-k\frac{dt}{dx}=w\,x$$

Integrating from $x=o$ to $x=d$

$$+k(t_o-t_d)=\tfrac{1}{2}\,w\,d^2$$

But $w\,d$ = energy dissipated per second per unit length and unit width of filament in calories—hence

$$k(t_o-t_d)=\frac{1}{4.2}\,\frac{\text{total watts}}{\text{breadth}\times\text{length of filament}}$$

$$=\frac{W}{b\,l}$$

so that: $t_o-t_d=\tfrac{1}{2}\dfrac{d}{k}\dfrac{W}{b\,l}$.

In our case

$$W=8.6,\qquad d=0.0035\,\text{cm},\qquad b=0.6,\qquad l=2.8\,\text{cm};$$

data as to k for platinum near the melting point are not available, but using the value $\dfrac{.18\ \text{gr. cal}\times\text{cm}^2}{\text{cm}\times{}^\circ\text{C.}}$ corresponding to 100° C. the computed value of t_o-t_d is 0°.05 C. It is evident that even with a filament three times as thick, and supposing the conductivity at 1600° to be only $\frac{1}{8}$ as great as at 100°, the error due to this cause would be only 0°.75, which for temperature measurements above 1000° C. is not a serious error. Moreover, if the conductivity is approximately known, this error can approximately

be allowed for. For materials having very much poorer conductivity—for example, carbon—or which must be used of much greater thickness, the conductivity correction as above computed may amount to considerable and, in the absence of data on the value of k at these high temperatures, must be determined experimentally, preferably by observations on wedges with three different thicknesses of walls, graphically extrapolating to the case of zero thickness. Our observations indicate that this extrapolation can be quite accurately carried out, and it also seems probable that by comparison of the observed apparent temperature-differences between inside and outside, for various wall thicknesses with those computed as above, approximate values of the thermal conductivity k may be obtained at high temperatures beyond the range of the usual methods.

In order to test the degree to which the conditions assumed in this discussion could be easily realized in practice, I have carried out, with Mr. Forsythe's assistance, observations upon wedge filaments of pure platinum. We first determined the melting point of platinum by observing with an optical pyrometer on the inside of the wedge as the temperature was slowly raised to the melting point. The mean of several observations gave 1747° C., 8° below the correct value (1755°)—but quite a satisfactory agreement considering the impossibility of getting accurate pyrometer settings at the instant of melting. As a second test we determined the relation between the true and corresponding black-body temperature for platinum, by simultaneous observations on the inside and outside of the wedge. With very thin platinum foil (0.007 mm) it was difficult to get a properly formed wedge, but with a sheet 0.032 mm thick, burnished fairly flat and polished on the outside, the observations shown in Fig. 4 were obtained. They agree almost exactly with those of Waidner and Burgess[1] (shown by the line) which are the mean results of several methods. These results demonstrate, I think, that it is easy to realize the assumed conditions and thus to obtain accurate measurements of the true temperature of a radiating surface.

The device shown in Fig. 1 is a convenient one for use with filaments which can be heated in air, enabling them to be kept

[1] *Bulletin of the Bureau of Standards*, **3**, 202, 1907.

straight and taut when heated. Turned on its side it forms an optical meldometer for determining the melting points of substances placed upon the face. Wedges of thin platinum (0.01 mm) used in air showed some difference in temperature between the "open" and "closed" side of the outer surface, due to greater loss

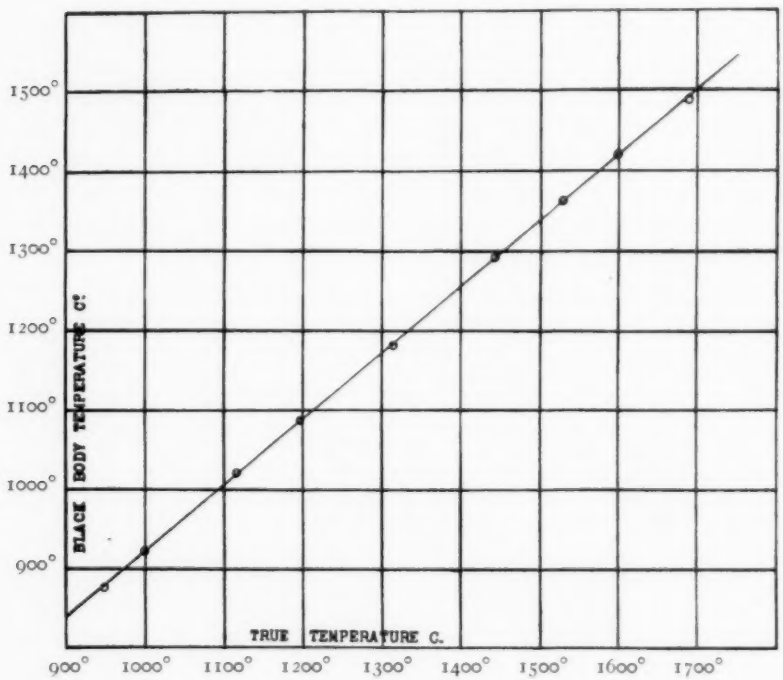


FIG. 4

of heat by convection currents at the opening. With the thicker walls (0.032 mm) this difference had almost disappeared, and was never noticeable in vacuum work. Moreover by sighting, inside and outside, at the middle of the face, this error can be minimized. If made with rounding apex these wedges often show a slight dark streak where the reflecting surface is normal to the opening, as would be expected.

SUMMARY

A discussion of the emissivity of a wedge-shaped aperture, particularly one with reflecting walls, and of the conduction of heat through the walls, leads to the conclusion that optical pyrometer observations on the inside of the wedge would give the true temperature of the outside surface. This is verified by experiment. The device is suggested as a simple means of accurately determining the true temperature of a radiating surface.

UNIVERSITY OF WISCONSIN
DEPARTMENT OF PHYSICS
December 1910

THE SPECTRA OF SOME GASES IN THE SCHUMANN REGION

By THEODORE LYMAN

This paper contains the results of an investigation on the nature of the radiation from oxygen, hydrogen, nitrogen, helium, and argon in the region of very short wave-lengths. The writer has already published a preliminary report on the subject.[1] Taken in connection with the measurements of the spectra of hydrogen[2] and carbon[3] monoxide, the investigation is intended to complete the study of gas spectra begun by Schumann.[4]

In work on spectra of gases, even more than in most other physical investigations, the value of the results depends on the excellency of the technique. A detailed account of the methods employed, therefore, will be found at the end of this paper. The results themselves are as follows:

The cases of helium and oxygen are easily dismissed. No spectral lines belonging to these substances have been discovered in the region of wave-lengths more refrangible than λ 1900. That is to say, the radiation from these gases, if any exists, is too feeble to be detected by the methods used in this research.

There are two spectra of nitrogen in the region under consideration: the one consists of faint bands with the heads directed toward the more refrangible end of the spectrum, the other is made up of two pairs of sharp lines. The first spectrum is produced when no condenser is included in the discharge-tube circuit. The second is faintly visible under the same conditions but is very much enhanced by the introduction of capacity. No mention was made in the preliminary report of these spectra, for the band spectrum was so feeble that it escaped detection for a long time, while the line spectrum was wrongly attributed to another element.

[1] *Jahrbuch der Radioaktivität*, **4**, 246.

[2] *Astrophysical Journal*, **23**, 181, 1906.

[3] *Proc. Am. Acad.*, **45**, 315, 1910.

[4] *Smithsonian Contributions*, No. 1413.

Argon yields no lines corresponding to the red spectrum in this region but a considerable number of lines exist in the blue spectrum. In other words, if the discharge tube contains argon at a pressure of 1 or 2 mm, and if there is no capacity in the circuit, then no lines can be observed on the more refrangible side of λ 1900. On the other hand, if a disruptive discharge is used, a considerable number of lines appear which extend throughout this spectral region. If the pressure in the discharge tube is increased to 1 or 2 cm and if the disruptive discharge is employed, the light given by the gas appears white to the eye. Under these circumstances, most of the lines disappear which were present at a lower pressure.

The spectrum of hydrogen gas has already been thoroughly investigated by Schumann and by the writer, but the existence of a primary spectrum, corresponding to that given by Balmer's formula, still remains in question. The writer has been unable to observe such a spectrum, while Schumann[1] states that, with a spark in hydrogen at atmospheric pressure, he has obtained lines which he believes belong to radiation of this type. The writer has repeated these experiments, using a spark 6 or 7 mm long with terminals of aluminum, copper, and iron in an atmosphere of hydrogen. Under these circumstances, with a disruptive discharge, the four-line spectrum of hydrogen is extremely strong and nearly overpowers the metallic lines, at all events in the visible region. Notwithstanding this, no primary spectrum lines have been obtained even after prolonged exposure.

As the writer has already mentioned in another place,[2] theoretical considerations would not lead one to expect that radiation of the Balmer type would exist in the region between λ 2000, and λ 1250, for the chief series given by Rydberg[3] lies on the less refrangible side of λ 2000, and the chief series, as given by Ritz,[4] lies on the more refrangible side of λ 1250. The first line of the latter series has a wave-length, according to Ritz, of λ 1215.3. This is in the region beyond the transparency of fluorite. It has

[1] *Astrophysical Journal*, **11**, 312, 1900.

[2] *Report British Association*, 1909, p. 132.

[3] *Astrophysical Journal*, **6**, 233, 1897.

[4] *Annalen der Physik*, **25**, 667, 1908.

not been possible to push the investigation of gaseous spectra with a disruptive discharge into this region because of experimental difficulties. The existence of this line, therefore, still remains in doubt.

Although the writer has been unable to repeat the observations of Schumann on the lines of the Balmer type, a singular spectrum apparently connected with that of hydrogen has recently come under his notice. If argon, containing a trace of hydrogen at a pressure of 2 or 3 mm, is inclosed in a tube with aluminum electrodes, and if no capacity is introduced in the circuit, a characteristic spectrum is obtained. It consists of five groups, each group containing five lines. These groups begin near λ 1650 and extend to λ 1450. They are all similar in appearance but they are not all identical in constitution. The distance between the lines in a group is of the order of from one to four Ångström units. If the last trace of hydrogen is removed from the argon, this spectrum disappears. Nitrogen, oxygen, and helium containing a trace of hydrogen and examined in a tube with aluminum electrodes do not produce these groups. If the argon and hydrogen are examined in a tube with iron electrodes, the intensity of the groups is very much reduced; if electrodes of copper are employed, the lines are extremely feeble. Under any circumstances, they are destroyed by the introduction of capacity. The most important fact in connection with these groups is that they are always found in the spectrum of pure hydrogen, no matter how this gas is prepared nor what electrodes are employed. In this case they are superposed upon a great number of other lines but they may be readily distinguished from the rest of the spectrum. All the groups can be identified in the reproductions of spectra published by Schumann;[1] the group which lies between λ 1590 and λ 1600 is the most striking, for at this point of the spectrum it is not obscured by the presence of strong lines. That these groups are not due to some impurity common to all the electrodes employed has been proved by using terminals of very pure silver furnished through the kindness of Professor T. W. Richards. The spectrum of hydrogen obtained with these elec-

[1] *Smithsonian Contributions*, No. 1413.

trodes is identical in every respect with the other spectra of this gas. If these groups are due to some impurity in the gas itself, such an impurity must be of a very fundamental character, for it was present in all the hydrogen which the author has employed during the past five years and it was present in the hydrogen used by Schumann.

It is conceivable that groups of this type may be present in the spectrum of argon, containing a trace of hydrogen, in the visible and ultra-violet regions. At first sight, therefore, a suspicion might exist that the "Groups of Four" observed by Rydberg[1] in argon might in reality be connected with hydrogen, but a comparison of the measurements of the argon and hydrogen spectra shows that such a suspicion is without foundation.

Kayser[2] has observed lines belonging to the spectrum of aluminum in the spectrum of argon when aluminum was used for electrodes, but it is obvious from what has just been stated that the Groups of Five observed in the Schumann region cannot be supposed to have a metallic origin.

Such, in brief, are the results of this investigation. Tables of wave-lengths are to be found at the end of the paper. A detailed description of apparatus and methods follows.

In this investigation, the writer's vacuum spectroscope was employed in a manner which has been already described elsewhere. To insure the purity of the gas under investigation, the type of apparatus shown in Fig. 1 has been finally adopted. The glass discharge tube of the usual form has a ground flange at its lower end. To this flange is attached a fluorite window by means of Khotinski cement, care being taken that the cement is applied only to the outside edge of the flange in order that none of it may come in contact with the gas. This window is indicated in the figure at *A*. The tube thus closed is fastened in a brass cone *B* by means of Khotinski cement. This cone fits air-tight into a cup *C* which in turn screws on to the face-plate of the spectroscope. Thus the gas under examination does not come in contact with the brass of the mounting. This is a considerable improvement over other

[1] Kayser, *Handbuch der Spectroscopie*, **2**, 577.

[2] *Astrophysical Journal*, **4**, 8, 1896.

arrangements. If extreme purity in the gas is not a requisite, it is convenient to attach the fluorite window directly to the botto n of the cup *C*, for with this arrangement the window can be readily cleaned by simply withdrawing the discharge tube.

The inlet of the discharge tube was connected with a U-tube 40 cm long which was plunged in liquid air. This device served as an effective trap for mercury vapor and for those carbon compounds whose spectrum has proved such an annoyance in former times. The U-tube in turn was connected with a spiral some 20 cm in length, to regulate the flow of gas, and this tube communicated with a suitable reservoir containing the gas under examination and with the mercury pump.

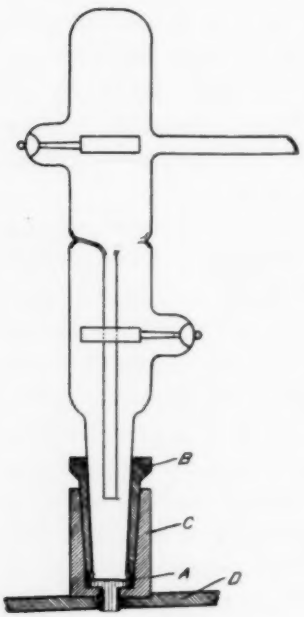


FIG. 1

The tube was excited by a small transformer, made by the Clapp Eastham Company, taking about six amperes in the primary on the 110-volt alternating circuit. The current through the discharge tube was usually between 10 and 15 milliamperes. When a disruptive discharge was desired, a spark-gap was placed in series with the tube and a condenser of 0.026 microfarad capacity was connected in parallel with the coil.

Measurements of wave-lengths were made by comparison with the hydrogen spectrum and the carbon monoxide spectrum, or with known lines of aluminum.

During the course of the experiments the appearance of the light from the discharge tube was frequently examined with a pocket grating spectroscope. The purity of the gas in the tube was estimated by the purity of its spectrum in the visible.

The gases used in this investigation have been prepared for the most part under the direction of Professor Baxter, to whom the writer is greatly indebted.

The oxygen was prepared by heating solid potassium permanganate, the gas was passed through plugs of glass wool, over platinized asbestos, through a wash-bottle and a tower containing potassium hydroxide solution, over solid potassium hydroxide, and finally over phosphorus pentoxide. The apparatus was constructed entirely of glass.

Some trouble was experienced in bringing the discharge tube into a condition which would remain constant from a spectroscopic point of view. A pressure of 5 mm was finally used. In addition to the precautions taken in preparation, the gas was sparked directly before it was admitted to the apparatus. Aluminum electrodes were used. No capacity, beyond that due to the leads, was included in the discharge-tube circuit.

The results were entirely negative, no lines could be attributed to oxygen in the Schumann region. The data collected some years ago in a preliminary investigation confirm this result.

Two specimens of helium were examined; the one was obtained through the kindness of Professor E. P. Adams of Princeton, the other was purchased from Tyrer of London. The latter specimen contained a slight trace of nitrogen which somewhat masked the spectrum of helium in the visible at pressures above 15 mm. At pressures below 5 mm, however, the helium lines appeared without any impurity other than a faint trace of hydrogen. Exposures were made with various pressures from 17 mm to 1 mm; the results of all these experiments were the same, no lines could be attributed to helium in this region; this result is confirmed by all data collected in preliminary investigations on this gas. Aluminum electrodes were used in all cases. Both an uncondensed and a disruptive discharge were employed.

The nitrogen used in the final experiments was made from a mixture of ammonium chloride, sodium nitrite, and potassium bichromate dissolved in water. The gas passed over potassium hydroxide, through concentrated sulphuric acid, and over phosphorus pentoxide, and finally over hot metallic copper.

Owing to the heating of the discharge tube, a gas pressure of 2 mm was selected for the final experiment both in the case of the disruptive discharge and when no capacity was in the circuit.

The feeble character of the band spectrum has been mentioned

already. The persistence of the line spectrum consisting of two pairs must be remembered also, for it was this persistence which prevented these lines from being ascribed to their true cause in the early part of the work. All the gases which have been investigated will show these pairs with a disruptive discharge if they contain a trace of nitrogen or even of air. Beside these pairs, there exist faint lines in this spectrum, but their intensity is so feeble that their wave-lengths have not been accurately measured. They are not included in the table.

Three samples of argon have been examined. The first was from Tyrer, the last was prepared as follows: air was drawn through towers containing solid potassium hydroxide. It was then passed over bright copper rolls properly heated, then through a tube containing two parts of magnesium powder, five parts of freshly ignited calcium oxide, and one-fourth part of metallic sodium free from oxide. After leaving this tube the gas passed over a combustion tube of copper oxide and was then collected over a solution of potassium hydroxide. The combustion tubing was heated electrically, which permitted the temperature to be conveniently controlled. The crude argon thus prepared was repeatedly passed over a mixture of lime and metallic magnesium until no further contraction took place. The gas was then mixed with oxygen and sparked in a tube over potassium hydroxide and mercury for several days. From here it was transferred to a new system and was passed repeatedly over phosphorus pentoxide and over a bright copper roll. The resulting gas showed no trace of nitrogen, hydrogen, or oxygen when examined spectroscopically in the visible part of the spectrum.

The final experiments were made with gas prepared as above described, but the results check very well with those obtained when the specimen from Tyrer was employed. The pressure ranged from 1 to 20 mm, depending on the nature of the discharge which it was desired to produce. Electrodes of aluminum, copper, and iron were used.

The wave-lengths of the lines in the "blue" spectrum of argon are to be found in the table on p. 107. Only three lines have been obtained in the white spectrum: of these, two are also found in

the blue spectrum; the gas at high pressures, therefore, appears to yield but one new line, λ 1650.0.

It is interesting to contrast the behavior of hydrogen with that of argon. With the former gas, a characteristic line spectrum is produced when no capacity is included in the circuit, while with a disruptive discharge these lines almost completely disappear and no new ones take their place. With the latter gas, just the opposite conditions prevail. Argon gives no lines in the Schumann region when the circuit is without capacity; it is only with a disruptive discharge that its characteristic lines appear.

The origin of the Groups of Five remains undetermined. As has been stated, these groups occur in all hydrogen spectra superposed upon a spectrum composed of fine lines. They have been included in all previous measurements. It is only when a trace of hydrogen is mixed with argon that the groups appear without the accompaniment of the lines. The fact that they do not occur as a separate spectrum when a trace of hydrogen is present in nitrogen, helium, or oxygen, would indicate that they are not due to an impurity contained in the walls of the tube. Moreover, experiments have been made in which the discharge tube was heated by the passage of the current until the capillary showed the sodium lines; such treatment in no way influenced the intensity of the Groups of Five when they were present. The nature of the electrodes affects their intensity, but they are not due to an impurity common to the various metals employed. This has been shown by the fact that they persist in the spectrum of hydrogen when the electrodes are of the purest silver.

The construction of these groups will appear from the following table. The lines of which they are composed are very sharp; they do not differ in character from the rest of the hydrogen spectrum.

GROUPS OF FIVE

Group	1	Diff.	2	Diff.	3	Diff.	4	Diff.	5
I.....	1643.0	2.5	1640.5	2.3	1638.2	1.7	1636.5	2.4	1634.1
II.....	1599.4	3.2	1596.2	2.6	1593.6	2.1	1591.5	2.5	1589.0
III.....	1550.6	3.6	1547.0?	3.1	1543.9	2.3	1541.6	2.4	1539.2
IV.....	.....	...	1495.5	3.6	1491.9	2.6	1489.3	2.4	1486.9
V.....	1445.2	4.2	1441.0	3.0	1438.0	2.8	1435.2	2.2	1433.0

In order of intensity these groups may be listed as follows, beginning with the greatest intensity: II, V, I, III, IV. Of lines in a single group the more refrangible are the stronger. The strongest line in the strongest group, 1589.0, has the intensity 8. Inspection of the columns which give the differences between successive lines in a group show that though the groups are similar they are not identical.

If these groups are compared with the Groups of Four in the ultra-violet, it is clear that the lines in a single group are much closer together than those in Rydberg's arrangement.[1] Even if the first lines in each group are taken as forming one system, the second lines as forming a second system, and so on, the results do not agree with the formula, for the new systems are not identical, and the frequency differences are not those given by Rydberg.

As to the cause of these Groups of Five there are obviously two opinions: either they are due to a very persistent and subtle impurity in the hydrogen, or they form a new spectrum of that gas.

The hydrogen used in the final experiments was produced electrolytically from a barium hydroxide solution; it was passed through distilled water, over solid potassium hydroxide, and was dried over phosphorus pentoxide. As to the spectrum of hydrogen there is little to add. The presence of moisture in the gas tends to enhance the primary spectrum in the visible; in the Schumann region it tends to weaken the many-line spectrum. The spectrum of hydrogen is sensitive to the smothering effect of a heavier gas. Nitrogen mixed with hydrogen weakens the spectrum of the lighter gas without contributing strong lines of its own.

The use of liquid air does away with mercury vapor in the discharge tube. When mercury is present, however, but one line can be attributed to it in this region, that at λ 1850.0.

In the tables which follow, the wave-lengths are in vacuum. Owing to the feebleness of the nitrogen bands, their position may be in error by four-tenths of an Ångström unit; the errors in the line spectra should not exceed two-tenths of a unit.

[1] Kayser, *Handbuch der Spectroscopie*, **5**, 69.

NITROGEN

Band Spectrum				Line Spectrum	
λ	I	λ	I	λ	I
1383.7	3	1687.5	2	1492.8 }	6
1393.5	2	1736.9	2	1494.8 }	5
1416.1	3	1752.9	3		
1431.6	2	1768.5	3	1742.7 }	7
1464.8	4	1804.7 ?	2	1745.3 }	6
1471.1	1	1821.1	4		
1501.1	3	1837.6	5		
1515.4	2	1854.0	3		
1530.6	2	1870.9	2		
1554.4	5				
1611.8 ?	4				
1672.3	3				

ARGON

"Blue" Spectrum

λ	I	λ	I	λ	I	λ	I
1333.7	5	1604.2	4	1827.6	6	1846.9	6
1334.5	7	1607.0	3	1830.6*	10	1850.2	4
1335.8	7	1611.0	4	1831.4*	9	1855.7	9
1460.1	5	1614.8	4	(1834.5)	2	1865.9	8
1463.3	3	1669.7	7	(1835.5)	2	1868.7	8
1465.6	4	1673.5	7	1836.3	9	1873.2	10
1467.9	2	1675.6	7	(1838.1)	2	1877.7	8
1589.5	4	1788.1	5	1839.2	9	1879.7	8
1600.7	5	1807.5	4	(1842.3)	1	1886.1	7
1602.6	2	1820.0	7	1843.1	9		

* Present in the "white" spectrum. ( ) Origin uncertain.

This research has been carried out in great part with the help of a grant from the Bache Fund.

Jefferson Physical Laboratory
Harvard University
December 31, 1910

CIRCULATION IN THE SOLAR ATMOSPHERE AS INDICATED BY PROMINENCES

By FREDERICK SLOCUM

In the course of the study of the solar prominences photographed with the Rumford spectroheliograph of the Yerkes Observatory, so many of the prominences presented the appearance of being driven to one side by a horizontal current that it seemed worth while to make a special study of these cases to see if they might not throw some light upon the circulation of the sun's atmosphere.

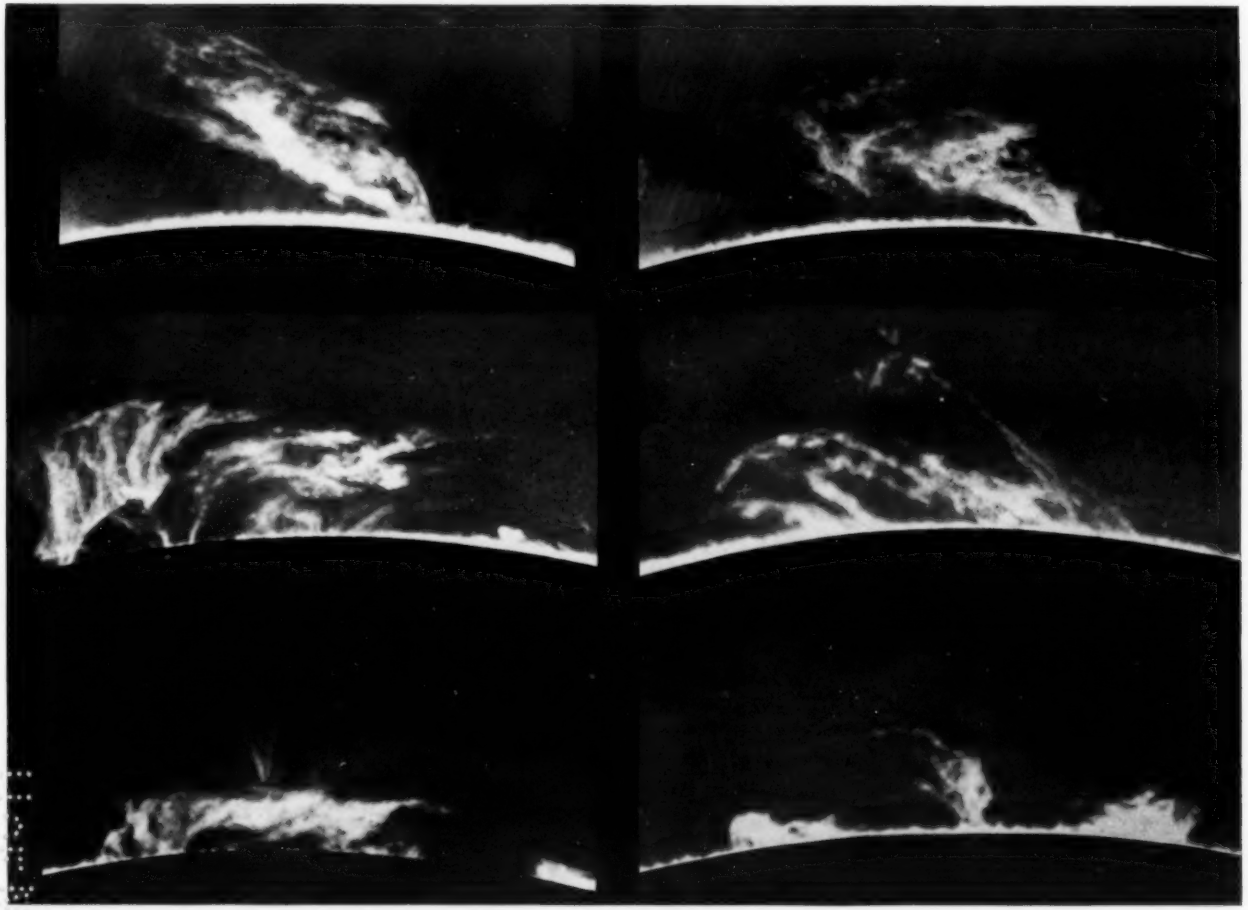
Photographs, in the light of the H line of calcium, of 3323 prominences, taken between January 1904 and December 1910, were examined, and of these, 1094, either by their shapes or movements, indicate a horizontal current. The prominences used as directional in the present investigation may be grouped under the following types:

1. Smoke-like
   a) as if rising from a fire (Figs. 1 and 2, Plate VII);
   b) as if coming from a chimney.
2. Bundles of filaments all bending in one direction (Figs. 3, 4, and 5, Plate VII).
3. Mass with streamers reaching out
   a) horizontally (Fig. 6, Plate VII, and Fig. 9, Plate VIII);
   b) curving down;
   c) curving up.
4. Clouds, detached, floating (Fig. 8, Plate VIII).
5. Treelike forms (Fig. 7, Plate VIII).

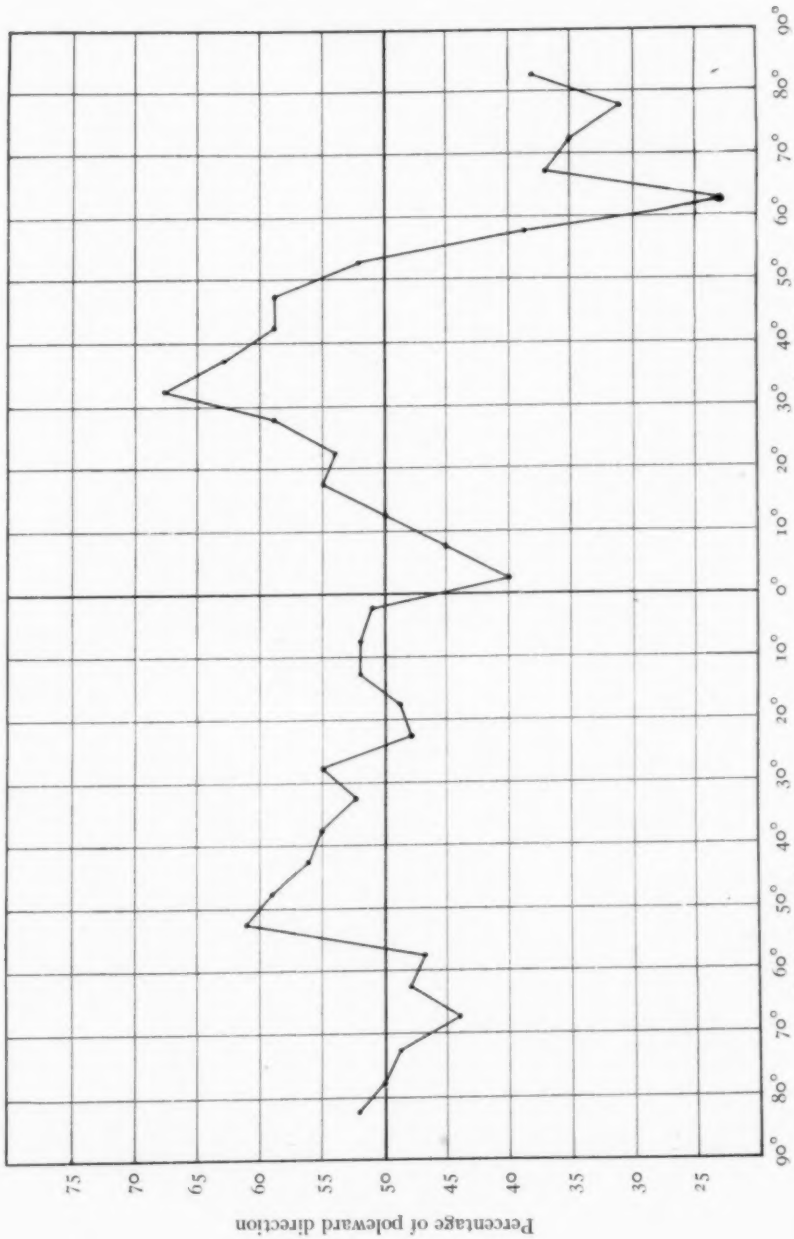
The "sky-rocket" on the extreme left of Fig. 12, Plate VIII, the "meteor" of Fig. 11, and the spike, or jet, of Fig. 10 are due to local explosions or eruptions, and prominences of this type were used only when the normal trajectory is evidently deformed by a lateral action.

The original tabulation contains the limiting latitudes of each prominence, the direction indicated, maximum height, and type of prominence. These values were summarized by counting the num-

PLATE VII



SOLAR PROMINENCES INDICATING HORIZONTAL CURRENTS



Percentage of poleward direction of solar currents as indicated by prominences.

ber of directional prominences in each five-degree zone from the north to the south pole. The results are given in the accompanying table. When a prominence extended over two or more zones it was counted in each zone, so that the sum of the numbers in the table is greater than the number of individual prominences. A percentage poleward less than 50 means an average tendency toward the equator, a value greater than 50 means a tendency toward the pole.

The results are shown graphically in the diagram. The abscissas are solar latitudes, the ordinates are percentage of poleward tendency. Points above the X-axis (percentage 50) indicate a tendency toward the pole, below the X-axis a tendency toward the equator.

The 1094 prominences used are distributed in height as follows:

Limiting heights	0′−1′	1′−2′	2′−3′	3′−4′	4′−5′	5′−6′	7′−8′
Number	719	330	36	4	3	1	1

In the original tabulation no discrimination was made between high and low prominences. The average height to which the prominences used extend is 0.′7, or 30,000 km, so that the table and diagram represent the average poleward components of the circulation of the sun's atmosphere from the surface of the chromosphere up to that height.

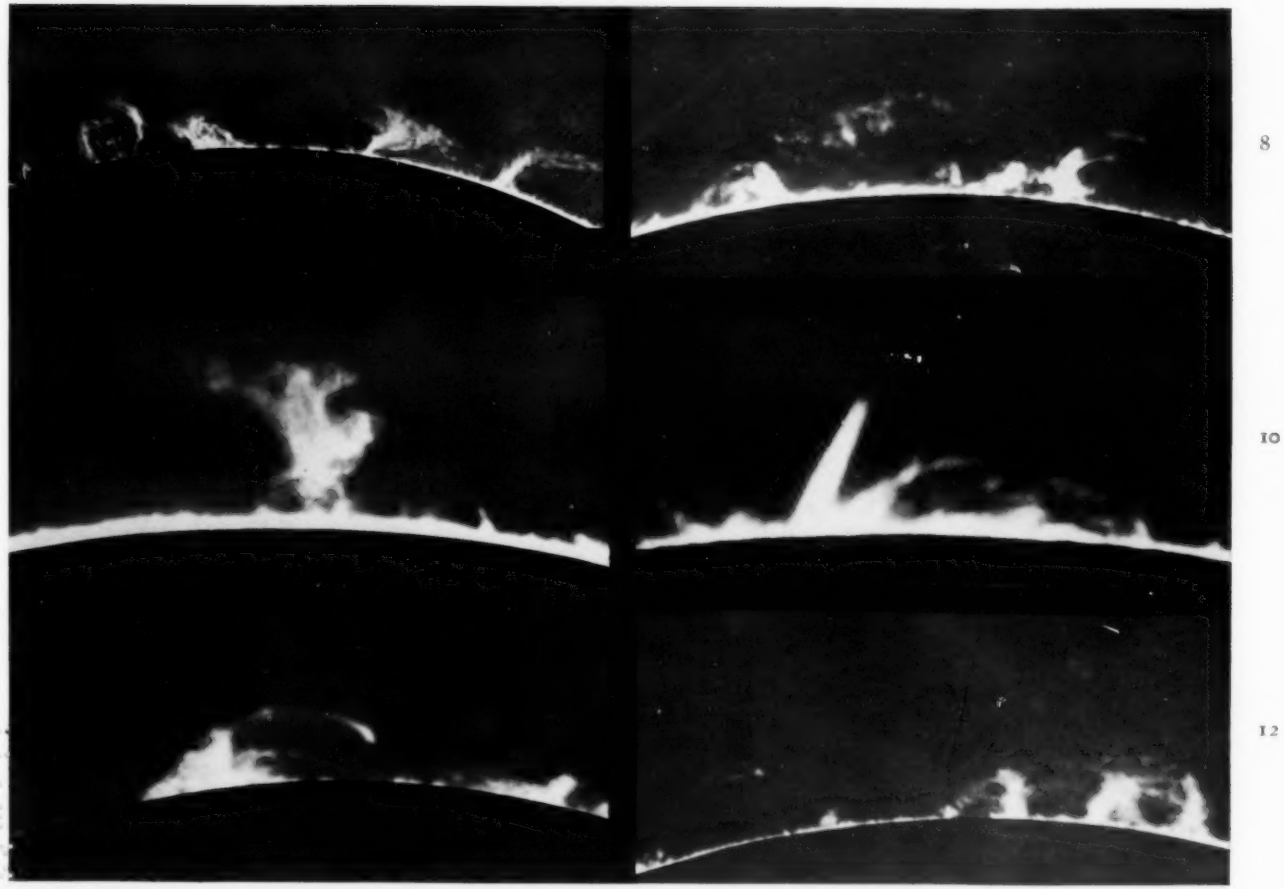
The following conclusions may be drawn from the diagram:

1. There is a tendency for movement toward the poles in middle latitudes: in the northern hemisphere between latitudes 15° and 55°, with a maximum of 69 per cent in latitude 33°; in the southern hemisphere between latitudes 25° and 55°, with a maximum of 61 per cent in latitude 52°.

2. There is a tendency toward the equator in high latitudes: in the northern hemisphere with a maximum of 78 per cent in latitude 63°; in the southern hemisphere with a maximum of 56 per cent in latitude 68°.

3. The conditions near the equator are practically neutral. There is a very slight apparent motion poleward from 0° to −15° and equatorward from 0° to +15°.

PLATE VIII



SOLAR PROMINENCES INDICATING HORIZONTAL CURRENTS

4. The contrast in tendency is greater in the northern than in the southern hemisphere in a ratio of at least 2 to 1.

Very few of the earlier plates afford data for determining velocities, but during the past year at least two prominence plates have been taken each day, if possible. Some of these have already been measured. Although it is not always easy to decide which movements shall be ascribed to local eruptions and which to general

TABLE I

APPARENT CURRENTS TOWARD OR FROM THE POLES, AS INDICATED BY PROMINENCES

Arranged according to heliographic latitude

LATITUDE	NORTHERN HEMISPHERE			SOUTHERN HEMISPHERE		
	Number		Percentage Poleward	Number		Percentage Poleward
	−	+		−	+	
85°–90°	1	0	..	2	1	..
80 –85	5	3	38	13	14	52
75 –80	9	4	31	20	20	50
70 –75	13	7	35	25	24	49
65 –70	17	10	37	24	19	44
60 –65	42	11	22	28	26	48
55 –60	46	30	39	31	28	47
50 –55	42	45	52	28	43	61
45 –50	27	40	59	36	52	59
40 –45	34	49	59	34	43	56
35 –40	33	57	63	38	46	55
30 –35	33	71	68	49	53	52
25 –30	34	49	59	44	53	55
20 –25	45	52	54	51	47	48
15 –20	39	47	55	48	46	49
10 –15	38	38	50	44	48	52
5 –10	39	32	45	37	40	52
0 – 5	39	26	40	33	35	51

+ indicates direction toward the pole. − indicates direction from the pole.

atmospheric drift, there are several of the type shown in Fig. 8, Plate VIII, which retain their form sufficiently to give an approximate value of their velocity, or rather the component of that velocity which is perpendicular to the line of sight. Ten such cases give values ranging from 0.5 km to 10 km per second. One detached cloud floating at a height of 442″, or 320,000 km, shows a velocity of 50 km per second.[1]

In a recent number of the *Astrophysical Journal*, Dr. St. John has

[1] *Astrophysical Journal*, **32**, 128, 1910.

given a résumé of the study of horizontal movements in the solar atmosphere.[1] None of the methods or results there mentioned are strictly comparable with those of the present paper. The older investigations were based upon the drift in latitude and longitude of sun-spots and faculae and therefore concern movements in the photosphere. The more recent observations of Deslandres and St. John involve the determination of radial velocities by the displacement of spectral lines. Both find evidences of a vertical circulation. The former says:[2]

> L'étude simultanée des vitesses radiales montre que la vapeur descend là où sont des plages brilliantes, facules et flocculi; elle s'élève au contraire sur les parties relativement sombres qui les entourent et surtout sur les filaments qui sont les parties les plus noires. Ces mesures décèlent les courants de convection, souvent groupés en tourbillons cellulaires juxtaposés, ainsi que dans les liquides.

St. John finds:

> The calcium vapor producing the absorption line K_3 in the solar spectrum has a descending motion over the general surface of the sun of 1.14 km per second in the mean, as indicated by the progressive increase in the wave-length of the absorption line in passing from the limb to the center of the sun, where the shift toward longer wave-length amounts to 0.015 Å. . . . .
>
> The calcium vapor to which the bright emission line K_2 is due has an ascending motion over the general surface of the sun of 1.97 km per second in the mean, as indicated by the progressive shortening of the wave-lengths of the emission line on passing from the limb to the center of the sun, where it reaches a maximum of 0.026 Å.[3]

These two results are apparently contradictory, but Deslandres has confined his attention to regions of local activity, while St. John, in attempting to represent the general conditions over the surface of the sun, has avoided such disturbances as far as possible.

In order to investigate the horizontal circulation, St. John has measured the wave-lengths of the K_2 and K_3 lines near the limb in the vicinity of the equator and of the poles. From the agreement of the two sets of measures he infers the "absence of currents of

[1] *Astrophysical Journal*, **32**, 59, 1910.

[2] *Annales de l'Observatoire d'Astronomie Physique de Paris (Meudon)*, **4**, 104, 1910.

[3] *Astrophysical Journal*, **32**, 79, 1910.

appreciable velocity parallel to the solar surface."[1] Near the pole the only current that could be detected by the spectroscope would be a horizontal current along a meridian. In any system of circulation upon à rotating sphere such a component would undoubtedly be a minimum at the poles, so the above test seems hardly sufficient to justify the general conclusion stated.

The equatorial regions should show a strong east and west component. This may account for a part of the consistent difference between the wave-lengths of K_3 derived from measures on the east and on the west limbs. This difference according to St. John is 0.0042 Å for latitude 6°.6, and 0.0062 Å for latitude 38°.4, the values for the west limb being the greater, indicating a westward motion at the level under consideration.

The extreme height of the absorbing calcium vapor which produces the K_3 line is about 1500 km[2] above the chromosphere, while the average height of the prominences used in the present discussion is 30,000 km, so that the conclusions stated probably apply to an upper current analogous to the terrestrial anti-trades. In a subsequent paper the material on hand will be discussed with respect to different levels, and an attempt will be made to introduce an east and west component by determining the drift of quiescent prominences in the line of sight.

TABLE II

Figure	Date	G. M. T.	Limiting Latitudes	Limb	Direction	Maximum Height		Taken by
							km	
1.....	1905 June 6	$5^h 15^m$	+30° +47°	W	P	187″	134,000	F
2.....	1905 June 5	10 6	+30 +48	W	P	150	108,000	F
3.....	1907 Oct. 2	5 37.6	+16 +44	W	E	126	90,000	F
4.....	1907 May 18	3 15	+15 +37	E	E	168	120,000	F
5.....	1907 Aug. 22	6 2.1	− 8 −25	E	E	48	34,000	S
6.....	1908 July 29	5 47.3	−14 −23	W	E	72	52,000	F & A
7.....	1907 Aug. 10	5 43.5	− 6 −28	E	E	78	56,000	F & S
	1907 Aug. 10	5 43.5	−33 −46	E	P	102	73,000	F & S
8.....	1908 July 14	4 36.4	−38 −64	E	E	96	69,000	F & A
9.....	1910 May 27	5 48.3	+ 4 +14	W	P	105	75,000	S
10.....	1908 Aug. 10	3 47.9	−20 −30	W	P	60	43,000	F & A
11.....	1907 June 29	5 27	−17 −30	E	E	72	52,000	F & S
12.....	1910 Mar. 15	7 36.6	− 4 + 2	W	P	60	43,000	S

Under Direction, P = poleward, E = equatorward.
Observers: F = Fox, S = Slocum, A = Abetti.

[1] *Op. cit.*, p. 80.

[2] *Op. cit.*, p. 81.

The accompanying table II contains data pertaining to the prominences of Plates VII and VIII. The figures are reproduced on quite different scales, but the relative amount of enlargement may be inferred from the curvature of the sun's limb, or may be accurately obtained from the dimensions given in the table. In this connection it should be noted that the data for Fig. 5 pertain to the low prominence. The jet near the center rising to a height of 2′ is apparently in the background and entirely independent. The data for Fig. 11 apply only to the meteor-like prominence, and in Fig. 12 only the "sky-rocket" shown faintly on the extreme left is considered.

YERKES OBSERVATORY
January 11, 1911

THE EFFECT OF TEMPERATURE ON THE IONIZATION OF A GAS

By J. HARRY CLO

The ultimate purpose of this experiment was to determine whether it is possible to change the kinetic energy of the molecule sufficiently to affect the stability of the atom. The ionization of gases was chosen as a type of the phenomena which involve the separation of the electron from the atom and which therefore depend on its stability.

The experiments made heretofore upon these phenomena may be divided into three classes, namely, those on the ionization of gases, those on the photo-electric effect of ultra-violet light, and those on the emission of electrons from radioactive substances.

H. L. Bronson[1] has shown that upon heating radium salts under conditions which eliminate radioactive transformations, volatilization of products, etc., the ionization of a gas by gamma rays is independent of the temperature of the radium. But the intensity of the gamma rays, and therefore their ionizing power, is generally believed to depend on the number of electrons given off per second from the radium. Hence it would seem to follow that the rate of emission of the electrons is not affected by the temperature. His observations extended from $-180°$ C. to $1600°$ C. and showed practically no variation greater than 1 per cent.

The expulsion of negative electrons from metals under the influence of ultra-violet light was shown to be independent of the temperature of the metal by Millikan and Winchester,[2] Ladenburg[3] and others. Millikan and Winchester made observations on different metals up to temperatures about $350°$ C. Ladenburg experimented on platinum, gold, and iridium, varying the temperatures from $20°$ C. to as high as $860°$ C. With platinum his results

[1] *Proc. Roy. Soc.*, A, **78**, 494, 1907.

[2] *Phil. Mag.* (6), **14**, 188, 1907.

[3] *Verh. der Deutschen Phys. Gesell.*, **9**, 165, 1907.

show no variation greater than about 5.5 per cent from the mean. For gold and iridium his results are even better.

The effect of temperature on the ionization of a gas has been investigated by J. Perrin,[1] McClung,[2] A. Gallarotti,[3] Herweg,[4] and Crowther.[5] With the exception of Perrin none of these experimenters found any systematic variation of the ionization. Perrin measured the ionization produced in air by Roentgen rays. Correcting for the variation of the ionization with density, he found it to be proportional to the absolute temperature. McClung investigated the phenomenon very thoroughly, using Roentgen rays as an ionizing agent. He measured the ionization in air, hydrogen, and carbon dioxide, working both at constant pressure and at constant density. His method allowed him to correct for the variation in the ionizing power of the rays. For air at constant pressure and at temperatures up to 272° C., he found the ionization to be constant to within about 6.5 per cent of the mean value. At constant density he found no greater variation in readings up to 201° C. For hydrogen at constant density his results show no variation greater than about 15 per cent up to 226° and for carbon dioxide no variation greater than 4.9 per cent up to about the same temperature. Gallarotti investigated the effect of temperature on the ionization of air at low temperatures. With X-rays his results show the ionization to be constant to within 2.5 per cent of the mean for temperatures down to −187° C. With radium he obtained measurements of the ionization at −10°, −60°, and −187° C., which did not vary more than 1.2 per cent from the mean.

These results show that there is no variation of the phenomena with temperature such as might have been expected from the results of Perrin on the ionization of gases. They show that for the temperatures considered, the rate at which the electrons are separated from the atom does not vary more than about 10 per cent in the case of solids and about 5 per cent in the case of gases.

[1] *Annales de Chimie et de Physique* (7), **11**, 496, 1897.

[2] *Phil. Mag.* (6), **7**, 81, 1904.

[3] *Atti della R. Accad. dei Lincei*, **16**, 297, 1907.

[4] *Annalen der Physik*, **19**, 333, 1906.

[5] *Proc. Roy. Soc.*, A, **82**, 351.

The kinetic theory, however, leads to the conclusion that the variation of the stability of the atom with temperature must be very slight and may even be beyond the limits of experimental determination. While the above results are consistent with this conclusion, they throw no light on the question as to whether a smaller variation takes place.

In the present experiment an attempt has been made, first, to reduce the observational errors with the purpose of measuring smaller variations than would have been detected in previous experiments, and second, to work at higher temperatures than had been employed in previous experiments on the ionization of gases.

The experiment was made upon gases for the following reasons: (1) According to the kinetic theory the molecular structure of a gas is simpler than that of solids and liquids. (2) The application of the fundamental concepts of the kinetic theory to gases has been more thoroughly demonstrated than in the case of solids or liquids. (3) The previous results on gases are not so accurate as some of the results on solids, and the experiments have not been made at as high temperatures as should be attainable.

OUTLINE OF EXPERIMENT

The observations consisted in the measurement of the ionization current in a gas within a closed vessel, by means of the rate of leak of a charge to an electrometer. An attempt was made to measure the ionization at constant pressure, but owing to variations and disturbances due to the change in density, this method was abandoned and all observations were made with the gas at constant density.

Air and hydrogen were the only gases studied. Radium was used as the ionizing agent. In all the observations recorded here the gamma rays were the only radiation entering the ionization chamber.

The current was measured with a quadrant electrometer of the Dolezelek type, arranged to have a sensitiveness of from 150 to 200 scale divisions per volt at a distance of 150 cm. With this sensitiveness the spot of light from the mirror moved one millimeter in from 0.1 to 0.2 seconds, a rate which varied in different series of obser-

vations. No observations were made in which the light did not move over at least 400 scale divisions.

The temperatures were measured by means of a gas manometer, whose minimum sensitiveness was about one-half millimeter per degree.

DESCRIPTION OF APPARATUS

The apparatus as shown in the accompanying figure is as follows: *C* is the vessel in which the ionization took place and whose temperature was varied. It was made from an iron cylinder of about

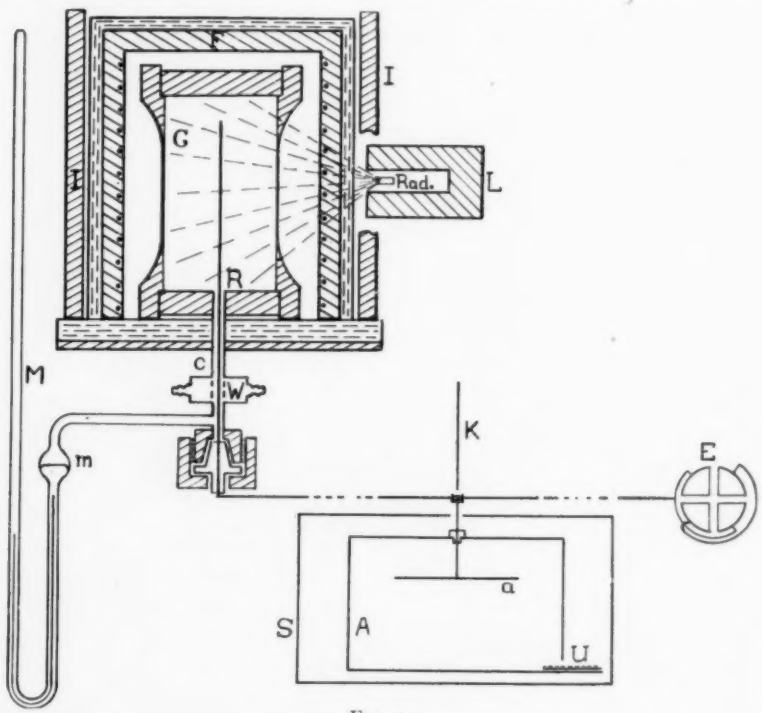


FIG. 1

11 cm internal diameter, by reducing the walls to a thickness of a millimeter or two everywhere except at the ends. The side through which the rays passed was further reduced. Ends of heavy iron plates were brazed to this wall, forming a cylindrical chamber of about 18 cm height.

The tube *c* leads downward to the manometer. It is surrounded by a water-jacket *W*. By means of the amber plug *p*, and the cap which presses the plug into position, it supports the rod *R* of about 2 mm diameter. This rod forms one electrode. The amber plug gave satisfactory insulation throughout the experiment.

The vessel *C* rested upon asbestos and an iron plate. Surrounding it was the electric furnace *F*. The furnace was surrounded by asbestos and the whole inclosed in an iron box *I*, with walls about 2 cm thick.

The manometer *M* was made of a graduated capillary tube. It was thoroughly cleaned and filled repeatedly with dry air before using. For convenience in placing it and in reducing the readings to degrees of absolute temperature, a bulb *m* was blown in the tube to form a reservoir for mercury, thereby keeping that arm of the mercury at very nearly a constant height. The whole air column was inclosed in a water jacket (not shown in the figure) to regulate and determine its temperature.

A is an auxiliary chamber. It consists of a metallic box in which a plate *a* is held insulated from the box by means of an amber plug. At the top of the rod which holds this plate is a mercury cup which, with the movable rod *K*, constitutes the earthing key of the system. This insulated system includes the rod *R*, the plate *a*, one pair of the electrometer quadrants, and the connecting wires. *U* is a layer of uranium oxide used to ionize the air in *A*. *S* is a metallic shield for *A*. *E* is the electrometer.

The radium was held in a lead block *L*, in such a position as would expose all parts of the gas chamber to the gamma rays. It was of sufficient strength to give, in this position, a measurable rate of deflection of the electrometer through 5 cm of lead.

The electrometer and all connecting wires were surrounded by earthed conductors to prevent leaks and electrostatic disturbances.

For the source of potential small storage cells were used. It was necessary that this potential be fairly constant. By letting the freshly charged cells discharge to that potential which remained constant for the longest time and using them in this condition, they were found to be all that was necessary.

METHOD OF OBSERVING, SOURCES OF ERROR

In taking the observations the method of procedure was as follows: The vessel C was repeatedly filled with the gas by exhausting and allowing the gas to flow in through drying agents. The temperature of the gas and the barometric reading were then taken. The reading of the manometer being taken at a known barometric pressure and for a known temperature of the gas in the manometer, the latter was sealed on to the chamber C. These readings were again taken. The values under these known conditions gave the constants of a reduction formula which in turn gave the absolute temperature in terms of the readings of the manometer and the temperature of the air in the manometer.

The needle of the electrometer was charged to a potential that would give the desired sensitiveness and at the same time minimize any errors due to the variation of this potential. The quartz fiber suspending the needle was made conductive by coating with a solution of zinc chloride. Although it was necessary to moisten the fiber every week or two, this method proved to be more satisfactory than any other.

The potential of the system was held at zero, while C was given a potential above or below this value. This potential was generally about 300 volts, a value well above that which would give a saturation current. A was held at a potential of opposite sign to that of C, and of sufficient value to give the saturation current caused by the presence of the uranium oxide in A.

To take a reading the radium was removed from its position near C, the uranium oxide from its position in A, and the system, insulated by opening the key K. Under ordinary conditions there would be a perfect balance of any small leaks and no deflection of the electrometer would result. If a charge leaked into the system from C, the uranium oxide was inserted into A sufficiently to cause a charge of opposite sign to pass into the system from A. By adjusting the position of the oxide the system could be kept at zero potential indefinitely. The radium was now placed in position and the rate of the deflection of the electrometer needle was measured.

In suitable weather no difficulty was encountered with electro-

static disturbances. It was seldom necessary to use the balancing device on account of failure of insulation. The insulation was always tested by keeping the system at zero potential for a period much longer than the time necessary for taking a reading. The absence of variations due to disturbances was considered sufficiently demonstrated when successive readings at constant temperature were found to agree as closely as it was possible to measure the rate of deflection.

The first difficulty that was encountered was one similar to the disturbance mentioned above as probably due to change in density. It was found that while the temperature of the gas was changing, except when that change took place very slowly, the rate of deflection of the electrometer was not constant but varied irregularly. Since this variation was absent when the temperature remained almost constant, it was considered due to some convective disturbance in the gas and was eliminated by slow and careful heating or by taking the observations at constant temperatures.

A second difficulty was found in the expulsion of ions from the hot metallic electrodes. This could not be overcome completely in the apparatus used for these observations. It was, however, partly overcome. This heat leak[1] was found to begin ordinarily at about 350° C., but, by prolonged or repeated heating at temperatures above this value, the temperature at which the leak first appeared was changed to about 450° C. Above this temperature it was always present. It was to meet this difficulty that the auxiliary chamber *A* was introduced into the system.

To measure the ionization under these conditions the temperature of the chamber *C* was first brought to as nearly a constant value as possible. With the radium removed, the position of the uranium oxide was varied until the system when insulated would remain at zero potential for a period at least several times as long as that required for a reading. The radium was then placed in position, the reading taken, and the balance again tested. If the balance was now disturbed enough to affect the reading by as much as 0.1 per cent the reading was discarded.

As is well known, a temperature is soon reached at which this

[1] Richardson, *Proc. Camb. Phil. Soc.*, **11**, 287, 1902.

leak increases very rapidly with the rise of temperature. At a temperature of about 650° C., it became impossible to keep the temperature sufficiently constant to be able to balance the leak for a period great enough to measure the ionization.

At temperatures above 600° C. the escape of the gas from the ionization chamber began to introduce another source of error. This difficulty alone was sufficient to limit the range of observations to temperatures around this value.

DISCUSSION OF READINGS, DATA

The results of some of the observations are shown in the accompanying tables. The rate of ionization of the gas, as represented by the rate of movement of the electrometer needle, is here expressed in millimeters per second. The rate in any one table is not to be compared with that in another table, as the sensitiveness of the instrument was not the same for the different series even when the same gas was used.

In Table I, columns I, II, and III show readings for air. Columns IV and V are for hydrogen. Columns I, II, and IV show individual readings only. It was impossible to work with hydrogen at as high temperatures as those reached in air because the convective disturbances were much greater than in air, and because the vessel *C* would not hold the hydrogen under as great a pressure as the air.

As one may see from the table, the individual readings for air are constant to within about 0.25 per cent from the mean for temperatures up to about 500° C. For hydrogen column IV shows about the same uniformity, but the readings were taken to about 425° C. only. While the individual readings of column III are not so nearly constant, the mean of the readings at each temperature shows a variation of only about 0.5 per cent from the mean up to about 615° C. In this series the readings at the highest temperature are subject to a slight correction on account of the leak of air from the vessel. Either this correction or the difficulty of keeping the temperature sufficiently constant would account for the irregularity in the readings at this temperature.

In general the readings agree as closely as those taken under the same conditions and at the same time upon the gas at room tem-

perature. Hence the readings agree as closely as the method of observation would warrant, upon the assumption that there should be no variation at all.

TABLE I

Air							Hydrogen				
I		II		III			IV		V		
Temp.	Rate	Temp.	Rate	Temp.	Rate	Mean	Temp.	Rate	Temp.	Rate	Mean
22°	7.93	20°	7.77	21°	5.66	....	10°	6.35	13°	6.39	....
	7.93	....	7.77	....	5.68	5.67	....	6.35	....	6.39	6.38
	7.90	....	7.78	....	5.65	....	....	....	....	6.37	....
	7.92	28	7.77	....	5.68	....	....	....	....	6.39	....
25	7.93	42	7.78	....	....	....	107	6.38	....	....	....
67	7.93	....	7.75	....	....	....	....	....	38	6.39	6.37
77	7.93	59	7.78	....	....	....	....	....	....	6.35	....
197	7.91	81	7.77	....	....	....	....	....	....	....	....
	7.90	94	7.77	....	5.65	....	116	6.38	144	6.35	....
200	7.92	106	7.75	396	5.66	....	....	....	....	6.38	....
	7.93	197	7.78	....	5.66	5.66	....	....	....	6.35	6.38
270	7.90	228	7.75	....	5.65	....	....	....	217	6.37	....
283	7.92	251	7.77	442	5.64	5.64	....	....	....	6.33	....
298	7.90	273	7.78	....	5.64	....	198	6.38	....	6.37	6.35
309	7.92	302	7.75	....	....	....	....	....	....	6.39	....
318	7.90	311	7.78	....	....	....	....	....	....	....	....
326	7.92	323	7.75	486	5.72	....	....	....	314	6.35	....
334	7.92	332	7.79	....	5.67	5.69	366	6.37	....	6.37	6.37
367	7.90	359	7.77	....	5.67	....	....	....	....	6.37	....
438	7.92	398	7.75	513	5.62	....	....	....	....	6.37	....
467	7.91	424	7.78	....	5.69	5.66	....	....	....	....	....
473	7.91	441	7.78	....	5.67	....	402	6.37	343	6.37	6.37
491	7.94	466	7.75	....	....	....	....	6.37	....	6.39	....
	....	497	7.75	613	5.47	....	....	6.37	....	....	....
	....	515	7.62	....	5.80	5.63	....	....	....	....	....
	....	....	....	....	....	....	429	6.35	413	6.47	....
	....	....	....	....	....	....	....	....	....	6.27	6.33
	....	....	....	....	....	....	....	....	....	6.27	....
	....	....	....	....	....	....	....	....	....	....	....

TABLE II

Mean Rate from	I′	II′	III′	IV′	V′
0°–100°	7.924	7.771	5.667	6.375	6.380
100 –200	7.915	7.765	.....	6.380	6.360
200 –300	7.913	7.766	.....	.....	6.365
300 –400	7.914	7.765	5.656	6.37	6.370
400 –500	7.920	7.765	5.663	6.365	6.334
500 –600	.....	.....	5.660	.....	.....

In columns I′, II′, III′, IV′, and V′ (Table II), the mean rate for one range of temperature of 100° is compared with the mean for

other equal ranges. It will be noticed that for the higher temperatures the mean rate is in general slightly lower. This is doubtless due to the difficulty in keeping the temperature sufficiently constant or in varying it slowly enough to avoid the disturbances due to convection currents in the gas.

SUMMARY

The temperatures were varied from room temperature to about 615° C. The absolute temperature and therefore the mean kinetic energy of the molecules was increased to three times its value at room temperature. From the kinetic theory it may be shown that about 1 per cent of the molecules have a probable mean energy four times this mean. Hence the energy of agitation of 1 per cent of the molecules was probably about twelve times the mean energy at room temperature.

Readings were taken nearly 300° C. above the temperature at which electrons are first driven from the metals by heating. Both hydrogen and air were experimented with, the latter furnishing a desirable mixture of gases of different molecular weights.

The individual readings were in general constant to within 0.2 per cent of the mean. In columns I′, II′, and III′ (Table II), which are mean readings for air, the greatest variation is a little over 0.1 per cent.

The ionization of air by means of the gamma rays from radium is therefore independent of the temperature of the gas to within 0.2 per cent up to about 600° C. For hydrogen the same independence is shown for temperatures up to about 430° C.

A variation of over 200 per cent in the absolute temperature of a gas does not affect the stability of the atom sufficiently to change the ionization by more than about 0.1 per cent.

In conclusion the writer wishes to express his thanks for their assistance and encouragement to Professor Michelson and the staff of Ryerson Physical Laboratory, and especially to Professor Millikan, under whose direct supervision this experiment was undertaken.

THE UNIVERSITY OF CHICAGO
January 26, 1911

THE PYRHELIOMETRIC SCALE[1]

By C. G. ABBOT and L. B. ALDRICH

When in 1902 solar constant measurements were begun at the Astrophysical Observatory of the Smithsonian Institution, two copies of Crova's alcohol actinometer were obtained, one of which was made for the Observatory under Professor Crova's own supervision. In a letter to Professor Langley he said of his instrument: "Une longue expérience m'a appris que, lorsqu'il est bien étalonné sur un actinomètre absolu quelconque, il donne des résultats tout aussi exacts que l'actinomètre absolu qui a servi à l'étalonner." He speaks as if absolute actinometers were common, but it is only after eight years of seeking that we are satisfied that we have one.[2]

At first, having no Ångström compensation pyrheliometer, an instrument somewhat like Tyndall's was constructed and used as a standard. This comprised a blackened copper box filled with mercury and having a mercury thermometer inserted to measure the rise of temperature of the box of mercury under solar heating. Numerous determinations of the capacity for heat (water equivalent) of the instrument were made by Dr. Benton (then of the Observatory), and it is on the pyrheliometric scale thus fixed that all of the "solar constant" observations given in Vol. II of the Observatory *Annals* are stated. We never were sure that this scale was within several per cent of the true one, for there were numerous sources of error almost impossible to estimate in employing the mercury pyrheliometer as a standard.

We soon found that it was more convenient for us to use the mercury instrument in daily observations than the alcohol actinometer of Crova; for we never mastered the art of easily keeping a thread of mercury in a good part of the scale of the alcohol thermometer. Furthermore we found, by consulting the tables, that the specific heat of alcohol varies rapidly with the temperature,

[1] Published by permission of the Secretary of the Smithsonian Institution.

[2] The earlier experiments made here to devise a standard pyrheliometer are described in Vol. II of the *Annals of the Astrophysical Observatory*, p. 39.

so that an unknown error is introduced by the unknown temperature of the instrument.

About 1904 Mr. Abbot conceived the idea of constructing a standard pyrheliometer comprising the following essentials. A cylindrical chamber of about the form of a large test-tube, and blackened within, has hollow walls adapted for the circulation of a liquid. The sun's rays shine into this chamber through a measured orifice, and heat the walls at the rear end. A stream of water flowing at a measured rate removes the heat as fast as formed, independently of its distribution within the chamber. Such heat as escapes capture at the rear end of the chamber will be gathered somewhere along the sides, excepting the negligible amount escaping at the front orifice. Four platinum wires bathed by the water, two at the entrance, two at the outflow of the stream, are joined with accessories to form a resistance thermometer. This serves to measure the rise of temperature of the water due to solar heating. By increasing the rate of flow the rise of temperature may be diminished until the escape of heat on the *outside walls* of the chamber becomes negligible. To prove that the heating is correctly measured, two electrical heating coils are introduced near the back of the chamber, one of which is far more favorably situated than the other to communicate to the walls any heat which may be formed in it. In test experiments heat may be introduced electrically in either coil in known quantity, and its amount measured, as if it were solar heat, by the resistance thermometer. The full recovery of such test-quantities of heat, whether from the favorably or the unfavorably situated coil, serves to prove the accuracy of the instrument.

Preliminary experiments at length justified the construction of one of these instruments, which is described in Vol. II of the *Annals of the Astrophysical Observatory*, pp. 39–47. Although this instrument worked well, its disagreement with the Ångström instruments of the Weather Bureau was so marked as to lead to a suspicion of its inaccuracy. Accordingly two other instruments of similar essential features, but differing in minor parts and in dimensions, were afterward constructed by Mr. Kramer after Mr. Abbot's designs.

In 1910 a long and thorough determination of all the electrical and other constants of these two new standard pyrheliometers, numbered II and III, was made by Mr. Aldrich. We were satisfied at its conclusion that no error in the readings of either instrument exceeding 1/500 could possibly occur from lack of accuracy in the determination of these constants. Secondary silver-disk pyrheliometer No. 8_{bis} was then compared with each of the two standards. In this comparison Mr. Fowle aided toward the last.

We do not give here the numerous details of the many measurements of electrical constants, and of the many pyrheliometer comparisons. These details will be given in Vol. III of the *Annals* of the Observatory. We remark that in Standard No. II the spiral channel in the hollow walls of the chamber is too restricted, so that about 60 feet head of water is required to force the stream of water at a proper rate (about 1 gram per second). In this pyrheliometer, also, the platinum thermometer resistance wires are too small in diameter and are probably swayed by eddies in the water-flow. In consequence of these defects there was considerable drift of the galvanometer to be contended with in the use of Standard No. II, so that more comparisons were necessary with it than with No. III.

The final results are as follows:

With Standard Pyrheliometer No. II: Sixteen comparisons on four different days with No. 8_{bis} give

$$\frac{\text{No. II}}{\text{No. } 8_{bis}} = 0.6289 \pm 0.0029 .$$

Electrical heating was introduced in No. II twenty-one times on six days. Percentage "found" ranged from 96.3 to 105.7.

$$\text{Mean} = 99.1 \pm 0.3 .$$

With Standard Pyrheliometer No. III: Six comparisons on one day with No. 8_{bis} give

$$\frac{\text{No. III}}{\text{No. } 8_{bis}} = 0.6287 \pm 0.0014 .$$

Electrical heating was introduced in No. III eight times on two days. Percentage "found" ranged from 98.6 to 99.9.

$$\text{Mean} = 99.25 \pm 0.13 .$$

From these comparisons with No. 8_{bis}:

$$\frac{\text{No. II}}{\text{No. III}} = 1.0003 \pm 0.0051 .$$

In the solar-constant work on Mount Wilson, secondary pyrheliometer No. IV has been read on every observing day since early in 1906. It was compared with secondary No. V at Washington in 1906, and with No. 8_{bis} on Mount Wilson in 1909. No. 8_{bis} was compared with No. V at Washington in 1910. Hence there were two ways of getting the ratio $\frac{\text{No. IV}}{\text{No. } 8_{bis}}$, one direct, the other by $\frac{\text{No. IV}}{\text{No. V}} \times \frac{\text{No. V}}{\text{No. } 8_{bis}}$. In the direct way we found $\frac{\text{No. IV}}{\text{No. } 8_{bis}} = 0.7353$. The other gives $\frac{\text{No. IV}}{\text{No. } 8_{bis}} = 0.7358$. From the mean of these:

$$\frac{\text{No. IV}}{\text{Standard}} = 0.8551 .$$

In October 1910 Mr. Abbot made a direct comparison on Mount Wilson between No. IV and Standard No. III. He obtained from eight observations on two days:

$$\frac{\text{No. IV}}{\text{Standard}} = 0.8581 \pm 0.00185 .$$

CONCLUSIONS

We believe of the two standard pyrheliometers, No. II and No. III, that each recovers and correctly indicates the heat received in test experiments with known quantities of heat electrically introduced, within less than 1 per cent.

As the heat electrically introduced must be communicated to the air of the chamber and thence to its walls before being taken up by the water stream, we believe that solar heating, which occurs on the walls themselves, may be correctly measured by both standards, and in our experiments was measured within 0.2 per cent.

This conclusion is supported by the agreement to within $\frac{2}{6290}$ of the comparisons of the two standards with Secondary No. 8_{bis}.

We regret that we cannot feel quite sure that No. 8_{bis} preserved

its constants unchanged in the journey from Mount Wilson to Washington, and we therefore assign the given ratio $\frac{\text{No. IV}}{\text{No. } 8_{bis}}$ little weight. We assign full weight to the given ratio $\frac{\text{No. IV}}{\text{Standard III}}$ obtained by direct comparisons of October 1910 on Mount Wilson.

We believe the scale of the solar-constant observations of the Astrophysical Observatory is thereby reduced to the absolute scale of calories (15° C.) per square centimeter per minute within a probable error of 0.2 per cent.

We incline to think that the unit of pyrheliometry furnished by new Ångström pyrheliometers is about 5.5 per cent greater than the true calory.[1] We do not state this unreservedly until confirmed by further comparisons.

ASTROPHYSICAL OBSERVATORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C.
January 30, 1911

[1] See H. H. Kimball, *Bulletin of the Mt. Weather Observatory*, **3**, Pt. 2, p. 84, 1910.

ON A QUANTITATIVE METHOD FOR DETERMINING THE SPECTRAL TYPES OF THE BRIGHTER STARS

By SEBASTIAN ALBRECHT

In 1906[1] the writer published a paper "On the Relation between Stellar Spectral Types and the Intensities of Certain Lines in Their Spectra." The basis for that paper was the discovery that the wave-lengths of certain spectrum lines varied in the different stellar spectral types, the variation being *progressive* as one proceeded from the F to the Mb types. At that time I believed that eventually it would be possible to invert the problem and, by means of the wave-lengths of the variable lines, to determine the spectral types of the stars. The study of the lines of variable wave-lengths was continued with various interruptions, and, when I had practically completed it, at Córdoba, for the region ordinarily used on the three-prism spectrograms on which λ 4340 is central, I decided to attack this inverse problem.[2]

The classification employed is the Draper classification,[3] which uses the letters O, B, A, F, G, K, M, and N to designate the sequence of the spectra. Numerals from 1 to 9 after the letter denote tenths of the interval between two successive letters; thus F8 designates a spectrum about eight-tenths of the interval from F to G.

To review briefly some of the results of the former paper: an examination of Rowland's tables shows that in most cases studied, if not in all, lines apparently single on the stellar spectrograms are in reality blends of two or more close components. The nature of the variations of the wave-lengths found is such as to indicate varying intensities of the same components, rather than the

[1] *Lick Observatory Bulletin*, No. 106; *Astrophysical Journal*, **24**, 333, 1906.

[2] I was engaged in this work when Professor Schlesinger's circular letter of November 7, 1910, reached me. In this letter I received my first information in regard to the appointment by the Fourth Conference of the International Union for Co-operation in Solar Research of a "Committee on the Classification of Stellar Spectra."

[3] *Annals of Harvard College Observatory*, **56**, 66.

presence or absence of different components in the different stellar spectral types. A comparison was also made with Adams'[1] list of sun-spot lines, and the indications were very strong that the physical conditions in the stars as we pass from the F (this may be extended to include the A type) to the Mb type vary roughly in the same direction as from the sun to the sun-spots. The results of the

TABLE I

OBSERVED WAVE-LENGTHS OF LINES VARYING PROGRESSIVELY WITH SPECTRAL TYPE

A	F	F5	F8	G	G5	K	K2	K5	Ma	Mb
4246.9	.996	.996		[G to K .972]			.959		.954	
54.5	.517	.520		.500	.499	.499	.479			
60.6	.629	.642		.671			.720			
67.1	.148			.051		.033	.021			
67.9	.857			.883	.922	.929	.990		.022	
74.9	.976	.955		.950	.954	.944	.946			
78.4	.338			.346	.373	.401	.374			
86.1						.163	.120		.077	
87.1				.145	.095	.126	.106	.095		
88.1	.076	.130		.136	.157	.164	.155			
93.2			.217	.234	.229	.245	.271			
4314.3	.350	.324		.344	.380	.367	.359			
15.1	.182	.182		.182	.144	.152	.141			.117
21.0	.018	.996		.984	.942	.920	.900			
25.1	.190	.186		.169	.205	.220	.234		.217	
31.8			.838	.798	.801	.782	.775		.775	
34.0	.990			.052	.083	.101	.106		.111	
40.6	.661	.655		.661	.657	.656	.644	.590	.593	
44.6	.493			.586	.597	.623	.623		.654	
52.0	.026	.024		.010	.015	.010	.005	.994	.981	.970
52.9	.935	.938		.949	.960	.972	.990		.009	
62.2	.299						.173			.135
90.1	.881			.095		.121	.143	.137	.154	.159
94.2	.242						.127		.107	
95.2	.235	.248		.258	.269	.272	.272		.277	.310
98.3	.333						.262		.206	
99.9	.951			.941	.900	.912	.902	.851		
4400.6	[F to G .587]				.672		.670		.680	
12.2	.096					.284	.319		.302	
16.9	.994		.994			.762			.740	
25.6	.582	.599		.640		.887		.908		
28.7					.736	.721	.652			.656
30.7	[F to G .791]					.741	.730	.689		
33.4			.391			.434	.440			
35.2	.139	.183		.187	.204	.217	.253	.242	.250	
57.6		.610				.680	.665	.653	.641	
64.7	.631	.773	.798				.900			
68.7	.648	.651		.666		.693	.711		.729	
69.5	.492			.564		.595	.620	.643		
73.0	.129			.975	.975	.000	.972	.938		.912

[1] *Astrophysical Journal*, **24**, 69, 1906.

former paper, as well as of this, depend not only upon the appearance of the lines but primarily upon quantitative measurements of their positions.

A large number of lines whose wave-lengths vary progressively with the stellar spectral type has been found in addition to those published in the paper referred to above. The attempt to deter-

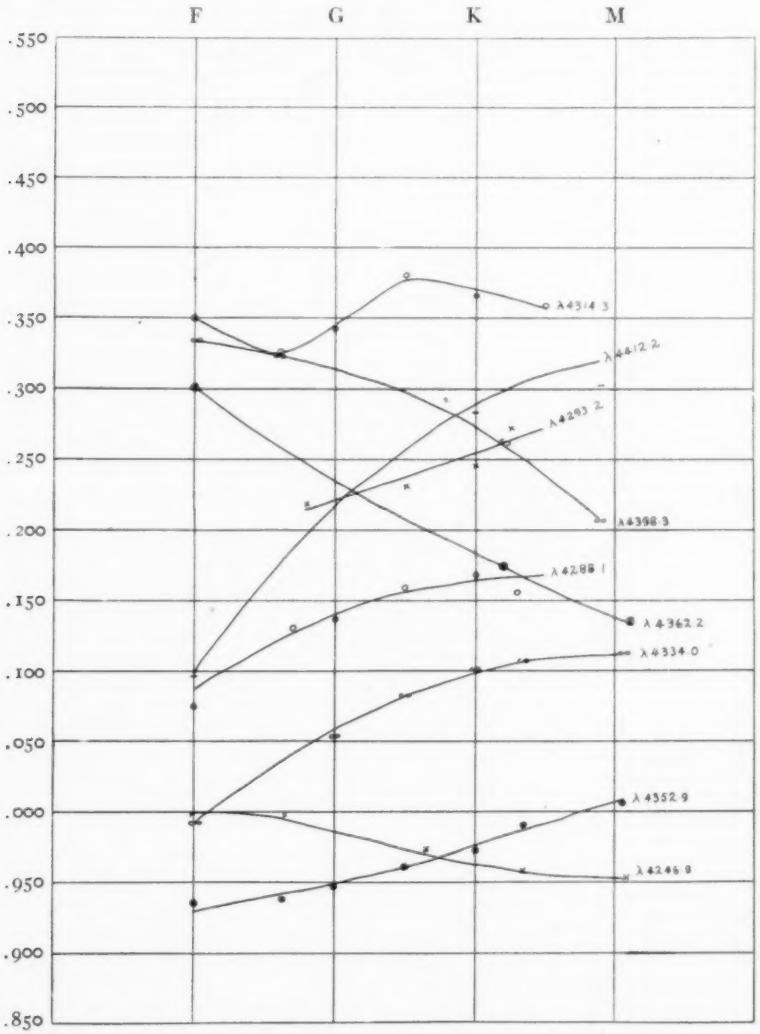


FIG. 1.—Curves for lines whose wave-lengths vary progressively with spectral type

mine the spectral types of stars by means of these wave-lengths was made for some Southern Mills spectrograms on which λ 4340 is central. For this purpose the more important of these lines between λ 4236 and λ 4480 were selected. In Table I are given the observed wave-lengths, in types F to Mb. These values were plotted with wave-lengths as ordinates and spectral types as

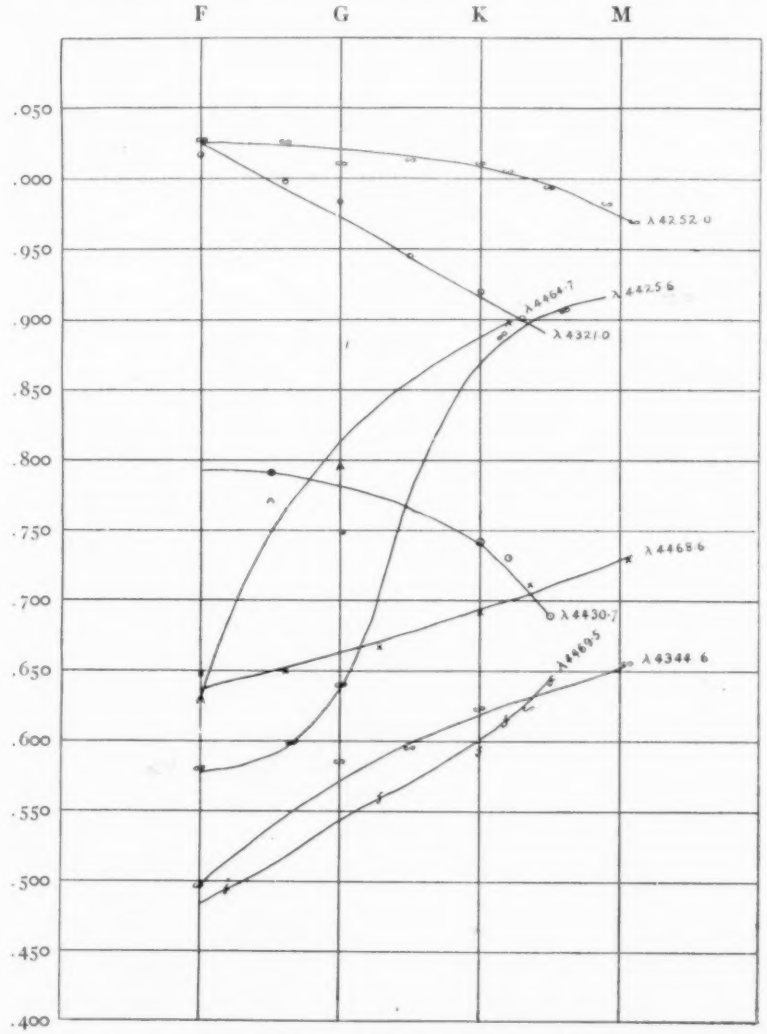


FIG. 2.—Curves for lines whose wave-lengths vary progressively with spectral tyep

abscissas. Some of these curves are reproduced in the figures. Table II gives the wave-lengths taken from the curves for each

TABLE II

WAVE-LENGTHS FROM CURVES FOR EACH TYPE

λ	F	F5	F8	G	G5	K	K2	K5	Ma	Mb	Average Deviation	Largest Deviation
4246.9	.999	.997	.992	.987	.974	.964	.960	.957	.955	.953	.001	.003
54.5	.518	.514	.511	.508	.500	.492	.488				.004	.008
60.6	.625	.643	.654	.663	.685	.710	.720				.005	.008
67.1	.122	.100	.086	.077	.055	.032	.022				.009	.026
67.9	.852	.870	.883	.892	.920	.951	.965	.986	.015	.030	.011	.022
74.9	.973	.960	.955	.952	.948	.947	.947				.002	.004
78.4	.319	.335	.346	.353	.370	.387	.392				.016	.020
86.1						.143	.126	.106	.084	.074	.006	.020
87.1				.145	.128	.112	.105				.006	.033
88.1	.086	.116	.132	.140	.154	.163	.165				.006	.010
93.2			.215	.221	.238	.255	.262				.008	.013
4314.3	.350	.326	.333	.344	.377	.370	.365				.002	.003
15.1	.191	.182	.176	.173	.162	.148	.143	.134	.122	.117	.006	.018
21.0	.025	.999	.982	.972	.945	.917	.905	.889			.004	.012
25.1	.190	.183	.181	.180	.204	.222	.225	.226	.221	.218	.003	.011
31.8			.819	.811	.793	.781	.778	.776	.774	.774	.004	.019
34.0	.990	.026	.046	.058	.083	.098	.103	.108	.111	.112	.001	.005
40.6	.660	.659	.659	.658	.656	.646	.639	.622	.59	.57	.008	.032
44.6	.495	.537	.558	.571	.599	.620	.627	.637	.650	.655	.006	.015
52.0	.026	.025	.022	.021	.017	.009	.004	.995	.980	.971	.001	.011
52.9	.928	.937	.944	.948	.961	.975	.981	.991	.004	.011	.002	.008
62.2	.300	.266	.247	.235	.207	.184	.175	.161	.144	.135	.000	.000
90.1	.88	.996	.035	.056	.096	.124	.132	.143	.154	.159	.004	.011
94.2	.240	.209	.190	.179	.154	.134	.127	.117	.107		.000	.001
95.2	.236	.245	.252	.255	.264	.273	.278	.283	.291	.295	.004	.015
98.3	.333	.325	.318	.313	.296	.272	.260	.239	.206		.000	.000
99.9	.953	.947	.940	.936	.922	.905	.896	.882			.009	.032
4400.6	.575	.595	.612	.622	.652	.672	.677	.682	.680	.676	.012	.026
12.2	.096	.162	.195	.214	.257	.290	.300	.310	.318		.009	.014
16.9	.999	.996	.988	.977	.92	.782	.758	.746	.739	.738	.002	.010
25.6	.577	.592	.613	.638	.770	.870	.888	.906	.916		.002	.004
28.7					.74	.706	.678	.655	.650	.649	.009	.015
30.7	.794	.791	.787	.784	.770	.741	.723	.690			.003	.007
33.4			.385	.395	.416	.434	.440				.000	.001
35.2	.142	.166	.181	.190	.211	.230	.235	.244	.254	.260	.006	.020
57.6			.610	.625	.659	.674	.669	.656	.644	.636	.003	.006
64.7	.631	.746	.790	.812	.855	.886	.899				.006	.028
68.8	.636	.650	.658	.664	.680	.695	.704	.714	.727	.735	.004	.009
69.5	.484	.510	.529	.541	.571	.601	.616	.643			.003	.006
73.0	.129	.050	.005	.978	.975	.994	.980	.949	.91	.90	.003	.017

type. In plotting the curves it was necessary to make an assumption in regard to the relative values of the intervals between types F and G, G and K, and K and M. These intervals were provisionally taken to be equal, and Ma and Mb were arbitrarily

placed 0.1 of an interval preceding and following the position of M in the scale. From the plots of a large number of the curves for the variable spectral lines, it may be possible later to determine the relative values of these assumed intervals. The curves at present available indicate that the intervals are approximately equal. I am now engaged in extending this work to the so-called "earlier" types and to about λ 4650, and shall accordingly delay the readjustment of the horizontal scale until the completion of that work.

Eight stars, one of which is our sun (spectrograms of *Venus* were used), were selected to illustrate the application of the method. The measured wave-lengths of the spectrum lines which vary progressively with the spectral type were compared with the curves for those lines to determine the corresponding values of the spectral type. Thus for each star the measured wave-length of each of these lines will furnish a value for the spectral type of that star. In Table III are given the results of this comparison. Column λ gives the wave-lengths of the lines employed. The quantities m are the values of the spectral type furnished by the individual lines in each star. The + and − signs indicate direction along the curves toward the right and left, respectively, counted from the G type for stars *a Fornacis* and the sun, from the K type for *a Trianguli Australis*, and from the F type for the remaining five stars. Column p gives the weights assigned to each line, and column pm gives the products of the two quantities. The results for each star are summarized at the bottom of the table, the last three lines giving respectively the probable errors in units of a tenth of the interval between the types represented by two successive letters in the Draper classification, the resulting spectrum type, and the type given in the Draper classification. These examples are merely illustrative of the method. The probable errors are somewhat large for several reasons. It is believed that it will eventually be possible to attain a considerable degree of accuracy. It is interesting to note that this method gives the position of the sun in the stellar classification as being very closely that of the G type.

The weights assigned are, to a certain extent, arbitrary, but in

TABLE III

SPECTRAL TYPE DETERMINED FROM CURVES FOR LINES VARYING PROGRESSIVELY IN WAVE-LENGTH

λ	α *Fornacis*			*b Velorum*			*Venus*			α *Trianguli Australis*			ι *Carinae*			α *Circini*			π *Sagittarii*			κ *Reticuli*		
	m	p	pm	m	p	pm	m	p	pm	m	p	pm	m	p	pm	m	p	pm	m	p	pm	m	p	pm
4246.9	− 6	1.3	− 7.8				+11	1.3	+14.3	− 3	0.8	− 2.4	+16	0.8	+12.8							+10	0.8	+ 8.0
54.5	+ 6	0.8	+ 4.8	+21	0.8	+16.8	+ 4	1.3	+ 5.2	+ 6	0.8	+ 4.8	+ 5	0.8	+ 4.0	+15	0.8	+12.0	− 4	0.8	+ 3.2	−22	0.8	−17.6
60.6	− 4	2.0	− 8.0	− 3	2.0	− 6.0				+ 4	1.7	+ 6.8	− 4	1.9	− 7.6				−16	1.5	−24.0	+ 5	1.7	+ 8.5
67.1										+ 5	1.5	+ 7.5												
67.9										+ 6	2.0	+12.0												
74.9	+ 1	0.9	+0.9				+ 1	0.8	+ 0.8	− 9	0.8	− 7.2	+11	1.4	+15.4	− 1	1.3	− 1.3	− 1	1.2	− 1.2	+ 6	1.4	+ 8.4
78.3				± 0	1.9	± 0.0				+ 1	0.8	+ 0.8	+ 8	1.4	+11.2									
86.1										± 0	1.7	± 0.0												
87.1							± 0	1.3	± 0.0	+11	1.5	+16.5												
88.1	− 1	2.2	− 2.2	− 1	2.7	− 2.7	− 5	1.7	− 8.5	− 6	0.8	− 4.8	− 3	2.2	− 6.6				+ 3	1.7	+ 5.1	+ 6	1.9	+11.4
93.2	− 1	1.5	− 1.5				+ 1	1.7	+ 1.7	+ 3	1.7	+ 5.1												
4314.3	− 4	0	....	+ 2	0	....	± 0	0.8	± 0.0	+ 2	1.2	+ 2.4	− 1	0.8	− 0.8				− 2			− 6	0	....
				or															or			or		
				+ 9															+13			+15		
15.1	−13	0.8	−10.2				−12	1.3	−15.6	+ 2	1.2	+ 2.4	+12	0.8	+ 9.6	− 5	0.8	− 4.0	+10	0.8	+12.8	+14	0.9	+12.6
21.0	− 1	2.2	− 2.2	+ 1	2.7	+ 2.7	+ 1	2.0	+ 2.0	− 2	2.2	− 4.4	+ 5	2.0	+10.0				− 2	1.7	− 3.4	+ 4	2.7	+10.8
25.1	± 0	0	....	± 0	0	....	± 0	0	....	− 1	0	....	+ 3	0	....							− 2	0	.....
																						or		
																						+13		
31.7	− 5	1.2	− 6.0							+ 5	0.8	+ 4.0												
34.0										+ 1	1.4	+ 1.4												
40.6							−12	0	....				− 6	0	....	−20	0	....	−20	0	....	+21	0	....
44.6				+ 1	2.7	+ 2.7	+ 4	2.4	+ 9.6	− 4	1.9	− 7.6												
52.0	+ 3	0.8	+ 2.4	−30	0.8	−24.0	± 0	0.8	± 0.0	+ 3	1.2	+ 3.6	+24	0	....	−40	0	....	+25	0	....	+ 3	0.9	+ 2.7
52.9	− 8	1.3	−10.4	+32	1.2	+38.3	+ 5	1.2	+ 6.0	+ 4	1.9	+ 7.6	+16	0.8	+12.8							+ 6	1.4	+ 8.4
62.2										+ 5	2.0	+10.0												
90.1										+ 5	2.0	+10.0												
4394.2				+ 5	3.0	+15.0				+ 4	1.5	+ 6.0	+ 1	2.0	+ 2.0									

| | | |

a general way account was taken of the slope of the curve at each spectral type, and, in the case of short curves, of the distance of the point from the nearest end of the curve. Other things being equal, points well within the ends of a curve will naturally give more reliable results than will those at the ends. The weights obtained in this manner were combined with weights proportional to the square roots of the number of observations.

TABLE IV

(SUMMARY OF TABLE III)

STAR	TYPE		
	Draper Classification	Value Obtained Above	Probable Error
ι *Carinae*	F	F 2.6	±1.0
α *Circini*	F	F 0.8	±1.7
π *Sagittarii*	F 2	F 4.3	±2.7
κ *Reticuli*	F 5	F 3.9	±1.1
b Velorum	F 5 Pec.	F 3.7 Pec.	±1.9
α *Fornacis*	F 8	F 6.7	±0.7
Venus	G(0)	G 0.3	±0.6
α *Triang. Austr.*	K 2	K 2.0	±0.5

For the F and M types, which are present at the extremities of the observed portions of the curves, the correction to the type obtained from the individual lines will frequently have to be taken by extrapolation at some distance from the observed parts of the curves. Consequently, the limits of the curves will be given especial attention in a later discussion of this problem.

Generally the steepest parts of a curve should yield more reliable corrections to the spectral type than the portions of the curve having a moderate slope. For example, from outstanding residuals from the steep portion of the curve for λ 4464.7, π *Sagittarii* had for some time been suspected of belonging more nearly to type F5 than to type F. I do not wish to attach much confidence to my value of F4, as the lines measured on the one spectrogram which I used were not especially suitable for this purpose. Frequently, however, at the steepest portions of some of the very steep curves the line was not included in the measures. At these points the relative intensities of the components change most rapidly with comparatively small differences in spectral type, and,

as such blends are comparatively wide and often fuzzy in appearance, the grain of the plate, underexposure, and overexposure will make it difficult to judge the position of the effective center of the blend. This "fuzzy" appearance of lines is, however, not confined entirely to the lines with steep curves.

The special aim has been to avoid the introduction of systematic errors. In this connection it has been especially gratifying that, for the variable lines, the wave-lengths for the G type as taken from the curves are in practically every case in fair agreement with the Rowland wave-length in the sun, giving the components of blends weights equal to their intensities in the sun. In the K types the wave-lengths of such blends are also in fair agreement with the wave-length resulting from blending the components according to their intensities in sun-spots.

The writer wishes to urge that in future measurements for radial velocities a number of favorable lines be included so that the same measures can later be used for the determination of stellar spectra without requiring the remeasurement of the spectrograms. For the region λ 4236 to λ 4474 I append such a list, Table V, both for lines with constant and with variable wave-lengths. This list will be extended later to about λ 4620. Even from the lines of variable wave-lengths the best ones can safely be used for radial velocity work if the proper wave-lengths for the type be selected. The writer's experience has been that such lines will frequently be among the best available. In fact, a knowledge of the behavior of a line in the various spectral types inspires a considerable degree of confidence in its use for radial velocity work.

It is probable that, for most of the brighter stars, the spectral type is known within a few tenths of a unit of the scale, so that the error introduced in taking the wave-lengths from the curves for a few of the lines measured will usually be balanced and will produce an inappreciable effect upon the radial velocity obtained from the plate.

The spectral types thus determined will be relative to the types of the stars used in obtaining the variations of the spectral lines. As it is desirable to have this basis rest upon a fairly large number

TABLE V

SUGGESTED LIST OF LINES TO BE INCLUDED IN THE MEASURES FOR RADIAL VELOCITIES

(The wave-lengths given in part *b* were determined from the stellar spectra)

λ	*a*, Lines Whose Wave-Lengths Vary	λ	*b*, Lines Whose Wave-Lengths Are Constant
4246.9	F to Mb	4245.435	F to Mb
54.5	F to K2	50.293	F to Mb
67.9	F to Mb	50.951	F to Mb
74.9	F to K2	71.319	F to Mb
88.1	F to K5	94.273	F to Mb
93.2	F8 to K5	4313.041	F to Mb*
4315.1	F to Mb	18.867	F to Mb
21.0	F to K5	28.101	G to Mb
34.0	F to Mb	37.223	F to Mb
44.6	F to Mb	39.721	F to Mb
52.0	F to Mb	76.103	F to Mb
52.9	F to Mb	79.364	G to Mb
90.1	F to Mb	83.725	F to Mb
95.2	F to Mb	4401.611	F to Ma
4425.6	F to Ma	06.803	F8 to Mb
30.7	F to K5	07.851	F to Mb
35.2	F to Mb	08.572	F to Mb
64.7	F to K2	27.444	F to Mb
68.7	F to Mb	42.526	F to Mb
69.5	F to K5	47.911	F to Mb

*May vary slightly.

of stars, and in order to eliminate systematic errors which may enter into the results on account of the dispersion, the slit-width, the kind of photographic plates, the grain and photographic treatment of the plates, a request has been sent to a number of observatories for the loan of a suitable series of spectograms. It is hoped that the results of that investigation will be ready for publication at an early date.

CÓRDOBA, ARGENTINA
December 26, 1910

PHOTOGRAPHIC OBSERVATIONS OF PROMINENCES[1]

By GIORGIO ABETTI AND RUTH EMILY SMITH

A photograph of the prominences is taken daily by Mr. Ellerman as a part of the regular work of the five-foot spectroheliograph connected with the Snow telescope[2] of the Mount Wilson Observatory. From 1906 to the beginning of 1908 the spectrum line used was the H line of calcium. On the latter date a series of photographs of the solar disk and of the prominences with the *Hα* line was begun; and since April 1908 only the *Hα* series, which gives better results, has been continued. The observations under discussion do not cover this interval completely, but combined with photographic and visual observations made elsewhere they will contribute to a more complete knowledge of the solar activity.

The reduction of the observations was made from the original negatives with the aid of a simple circle divided into degrees for determining the position-angle of the prominences, and for estimating their heights a millimetric scale was used. To determine the areas the method used for the flocculi was followed; that is, the prominences were cut from photographic prints and the total weight of the paper thus cut out was compared with the weight of a unit of paper cut from the solar disk.

A comparison was made between the Mount Wilson photographs and those taken at the Yerkes Observatory by Fox (aided in 1908 by Abetti) with the Rumford spectroheliograph attached to the 40-inch telescope. As the latter photographs were taken through the H line, the comparison with the *Hα* photographs of Mount Wilson is of especial interest. In the two instruments the scale of the solar image is almost the same. On the Mount Wilson plates 1 mm = 11″.2, and on the Yerkes plates 1 mm = 10″.6.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 51.

[2] *Ibid.*, No. 7; *Astrophysical Journal*, **23**, 54, 1906.

If P_0 be the position-angle of a prominence measured on the plate and read in the direction N.E.S.W., we must, to obtain the true position-angle of the prominence, apply to P_0 the orientation angle p of the telescope, which is experimentally determined by observing the transits of the solar image when the mirror of the coelostat is rotated. This angle varies by about 1° for different positions of the coelostat and for different hour-angles of the sun. By applying to the sum of P_0 and p the position-angle of the north point of the sun reckoned from the north extremity of the axis, with its appropriate sign, we obtain the heliographic latitude of the prominence. The latitude obtained in this way is but approximate, and agrees with the true figure only when this does not exceed 50° or 60°, according to the heliographic latitude of the center of the solar disk. For values exceeding this limit it is necessary to use the more accurate formula

$$\sin \lambda = \cos D \cos \chi,$$

λ being the required latitude, D the latitude of the center of the sun, and χ the position-angle of the prominence. This computation may be avoided by the use of Riccò's tables,[1] by the aid of which the latitudes given in the following tables have been corrected. The effect of refraction has not been taken into consideration because it is always smaller than the errors of measurement up to a zenith distance of at least 80°.[2] The quadrant to which the prominence belongs is indicated by the sign +, North, and −, South, combined with the column headings, East or West.

The width of the base of the prominence is reckoned in heliographic degrees, and the height in geocentric seconds. For the lower limit of height 30″ was taken in most cases, but at times prominences between 25″ and 30″ were noted. The direction of the prominences was also noted; that is, the inclination of the extremities of those prominences which do not emerge radially from the solar limb. In addition to the cardinal point, it is noted whether the prominence is directed toward the surface of the sun (down), parallel to it (||), or away from it (up). Thus some idea

[1] *Memorie della Società degli Spettroscopisti Italiani*, **10**, 21, 1881.

[2] See, for instance, *Greenwich Photo-heliographic Results*, 1905, p. ix.

is obtained as to the local disturbances to which the prominence is subjected owing to other peculiarities of the solar disk.

Besides the character of the prominences explained by the abbreviations on p. 148, the relation which probably exists between the prominences and the flocculi is given, deduced from an examination of photographs of the disk taken in calcium or hydrogen light. In various cases it is noted that bright flocculi are found on the sun's disk about the region where the chromosphere is disturbed by a prominence; but it is not to be concluded from this that a complete coincidence exists between the flocculus and the prominence because it is difficult to follow the former very close to the limb. This difficulty is still greater in the case of the dark hydrogen flocculi, which almost always, perhaps owing to lack of contrast, become invisible in the neighborhood of the limb. On the other hand, an essential difference must exist between flocculi and prominences if it is true that the maximum and the minimum of the prominence distribution in latitude do not agree with those of the flocculi. For instance, in the interval from July 1893 to September 1894,[1] while the maximum of the flocculi was in the zone 10° to 20° of latitude in both the northern and southern hemispheres, the maximum of prominences as taken from the observations of Tacchini[2] was in the zone 20° to 30° for both hemispheres.

The area of the prominences for each plate was expressed in hundred-thousandths of the visible hemisphere of the sun. This value was obtained by taking the ratio between the weight in paper, as cut from the prints, of all the prominences which were higher than 30″, and the weight of a square centimeter of the same print. This ratio, divided by the number of square centimeters contained in the visible hemisphere of the sun, and multiplied by 100,000, gives the desired value. With these quantities as ordinates the curve of the areas was obtained. The abscissas are dates, the intervals being one synodic rotation period of 27.5 days. The tables contain only those prominences with height and base equal to or

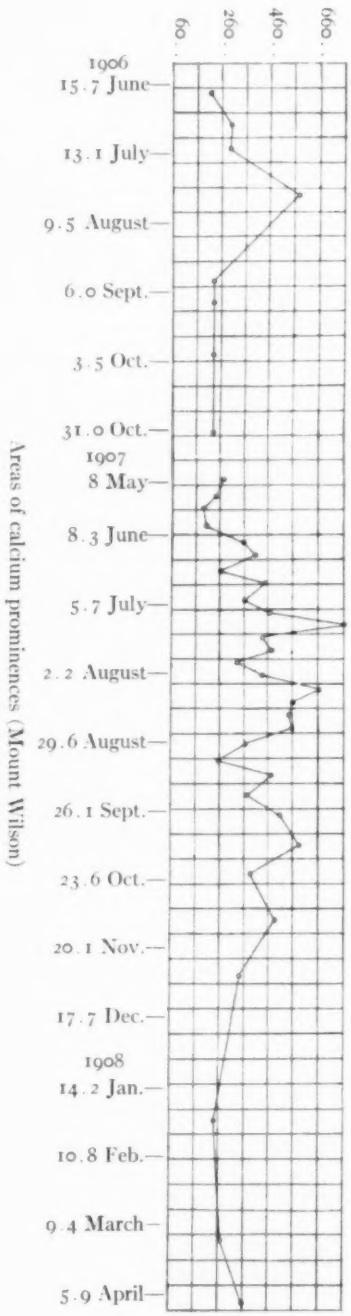
[1] Hale and Fox, "The Rotation Period of the Sun," *Publications of the Carnegie Institution of Washington*, No. 93, p. 46, 1908.

[2] *Memorie della Società degli Spettroscopisti Italiani*, **23**, 59, 67, 94, 121, 1894; **24**, 47, 1895.

exceeding 100″ and 10°, respectively. The record for the calcium prominences extends from June 1906 to April 1908; that for the *Ha* prominences from April 1908 to 1909. The results for the others have been collected for statistical and other studies and will be published when more material is available.

In Table III will be found the measurements made on prints of the Mount Wilson and Yerkes prominence photographs. Photographs of the same date are chosen for comparison and the time given is Greenwich Mean Time. The prominences common to the two places of observation, or assumed to be so, stand opposite each other in the table. The calcium prominences for both places are first compared, then the hydrogen prominences of Mount Wilson with the calcium prominences of the Yerkes photographs. Since the photographs of the two observatories were not taken at the same hour, considerable differences are found.

The mean height of the calcium prominences at Mount Wilson and at Yerkes is the same, 48″, while the *Ha* prominences at Mount Wilson have a mean height of 39″ and those of calcium at Yerkes 45″. Thus it seems that the



calcium prominences reach a greater elevation than those of hydrogen. This is also confirmed by the curve of the areas, which, throughout the period of observation, remains lower for the hydrogen than for the calcium. This result might also be produced by a decrease of the solar activity, but from an examination of the Catania observations this does not seem to be the case.[1] From the first quarter of the year 1908 to the second, in which the hydrogen prominence observations at Catania give very nearly a constant activity, the curve of the areas shows a mean daily difference of about 1/1000 of the visible solar hemisphere between the hydrogen and the calcium prominences, the area of the former being less than that of the latter. Making further a comparison between the Mount Wilson photographic and the Catania visual observations we find that the calcium prominences at Mount Wilson are about 40 per cent more than the hydrogen prominences at Catania, and that those of hydrogen at Mount Wilson are about 5 per cent less than those at Catania. The mean height of the calcium prominences at Mount Wilson (56″) is 7″ greater than that of the hydrogen prominences at Catania (49″), while the heights of the hydrogen prominences are in both places equal. This agrees well with the results of Fenyi[2] and Riccò.[3] As to the structure of the prominences, the filamentous appearance is seldom to be seen in the photographs either in the hydrogen or in the calcium; but it is probable that this peculiar structure is too difficult to be recorded ordinarily, owing to the exceptionally favorable atmospheric conditions together with the extreme regularity in the movement of the spectroheliograph which are required.

The results in the table giving the number of prominences in zones of 10° of heliographic latitude have been used to form curves, with the latitudes as abscissas and the number of observed prominences as ordinates.

Comparing the results of the Catania observations made during the same, or almost the same periods with these curves, it seems probable that the calcium prominences have a slightly different

[1] *Memorie della Società degli Spettroscopisti Italiani*, **37**, 87, 1908; **38**, 92, 1909.

[2] *Ibid.*, **37**, 114, 1908.

[3] *Ibid.*, **38**, 75, 1909.

distribution from those of hydrogen, i.e., the regions of maximum and minimum activity do not correspond in the two cases. Taking into consideration the fact that the Catania observations extend only through the second quarter of 1908, the later observations being not yet available, we see a better agreement between the curves for the hydrogen prominences observed at Mount Wilson and Catania than between those for hydrogen and calcium.[1]

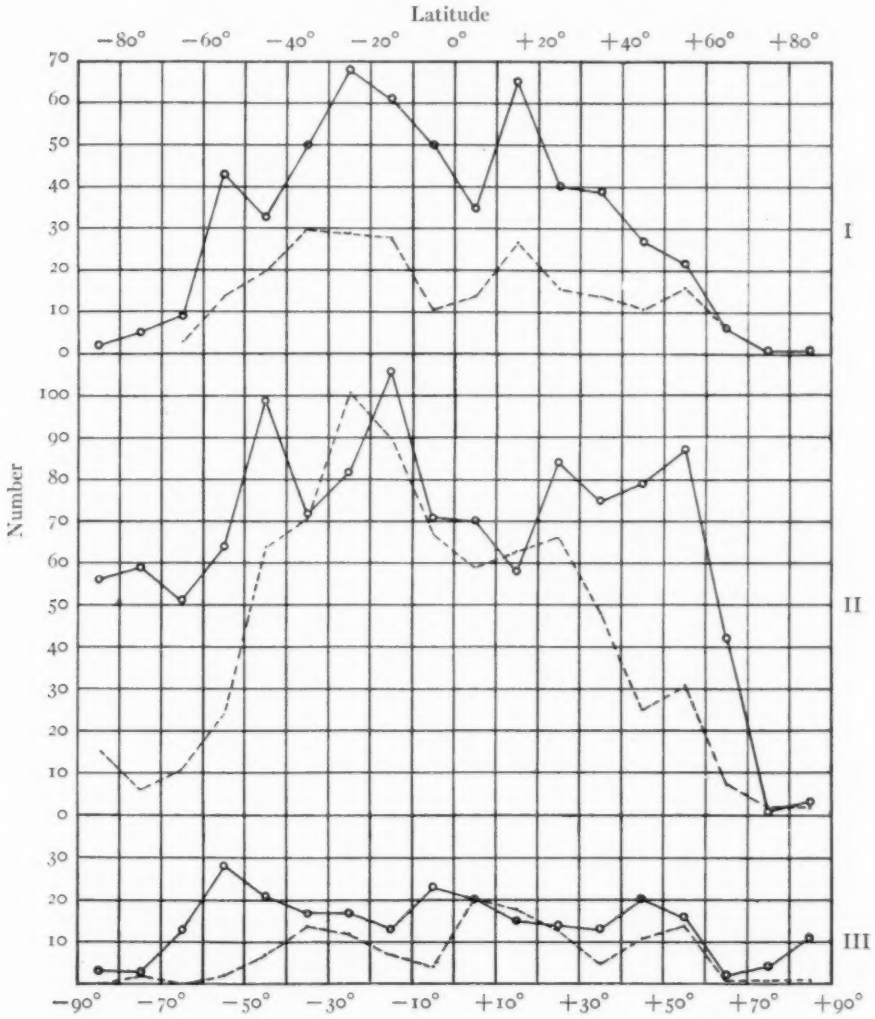
NUMBER OF PROMINENCES

MOUNT WILSON

Heliographic Latitude	June 15, 1906, to November 11, 1906 Calcium	May 15, 1907, to April 25, 1908 Calcium	March 30, 1908, to April 1, 1909 Hydrogen
Northern			
90° to 80°	11	3	1
80 to 70	4	1	1
70 to 60	2	42	6
60 to 50	16	87	22
50 to 40	20	79	27
40 to 30	13	75	39
30 to 20	14	84	40
20 to 10	15	58	65
10 to 0	20	70	35
Southern			
0° to 10°	23	71	50
10 to 20	13	106	61
20 to 30	17	82	68
30 to 40	17	72	50
40 to 50	21	99	33
50 to 60	28	64	43
60 to 70	13	51	9
70 to 80	4	59	5
80 to 90	4	56	2
Days of observation	39	157	126

Among the peculiar cases, those of July 17, 1907, Plate 2264, and August 11, 1907, Plate 2501, are worthy of note. In the first, between the two prominences at $-41°$ and at $-73°$ of latitude, East, a large arch is seen suspended above the chromosphere. Since there is a prominence on the plate of the preceding day (Plate

[1] A later comparison with the following Catania observations to the end of 1908 (*Memorie*, **38**, 159, 1909) confirms the above result. The maximum number of hydrogen prominences is at $+15°$ and $-25°$ for Mount Wilson and Catania; for the calcium prominences (Mount Wilson) there are two maxima in each hemisphere, at $+25°$, $+55°$ and $-15°$, $-45°$.



Distribution of the prominences in latitude

—o— Mount Wilson. Hydrogen in curve at top, calcium in lower curves

..... Catania. Hydrogen in all curves

I. Mount Wilson: March 30, 1908, to April 1, 1909. *H*
Catania: April 1, 1908, to June 30, 1908. *H*

II. Mount Wilson: May 15, 1907, to April 25, 1908. *Ca*
Catania: May 15, 1907, to March 30, 1908. *H*

III. Mount Wilson: June 15, 1906, to November 11, 1906. *Ca*
Catania: June 1, 1906, to December 31, 1906. *H*

2255) at $-74°$, it is more probable that the two prominences represent two independent objects, than that the prominence at $-73°$ is the extremity of that at $-41°$ bending down to the limb of the sun. From an examination of the photographs of the calcium flocculi taken on July 16 we see half-way between the two prominences very near to the limb of the sun a **V**-shaped dark flocculus about 35″ long; and both prominences seem to be bent toward the place where the flocculus was on the preceding day. Almost a full rotation after this we find a similar case in the same region. At the same latitude, $-41°$, on August 11, 1907 (Plate 2501), there appears a prominence 100″ high from which a long arm extends toward the east and seems to be falling on to the chromosphere at $-26°.5$. In the photograph of the disk taken 3 days later (August 14, Plate 2520) a spot is seen at the same latitude (between $-24°$ and $-31°$) surrounded by very bright flocculi. Of course we cannot be sure that the prominence arch whose extremity is at $-26°.5$ has its base at $-41°$, because it may well be possible that the matter itself is coming from $-26°$, but from an examination of the plates the former supposition appears the more likely.

It is through the careful discussion of observations of this kind, made both visually and spectrographically at as many stations as possible, well distributed in longitude, that we may hope materially to extend our knowledge of the varying phenomena of solar activity.

ABBREVIATIONS[1]

u	= up	n n	= very nebulous
||	= parallel	n f	= nebulous and filamentous
dw	= down	f	= filamentous
a v	= fairly bright	f f	= very filamentous
v	= bright	d	= faint
v v	= very bright	d d	= very faint
n	= nebulous		

[1] See *Memorie della Società degli Spettroscopisti Italiani*, 1, 55, 1872.

TABLE I

CALCIUM (H) PROMINENCES

Height ≷ 100″, or Base ≷ 10°

PLATE NO.	DATE	P.S.T.	NO. PROM.	HELIOGRAPHIC LAT. QUADRANT		BASE	HEIGHT	DIRECTION	REMARKS
				East	West				
	1906								
492	June 29	6^h50^m	1		−36°	2°.7	110″		
			10	+ 8°		10.0	55		bright floc.
500	June 30	6 50	3		+ 7	10.0	30		
552	July 8	17 24	7		+45	10.0	77		
564	July 10	6 49	5		−13	10.0	44		
			6		+ 4	15.0	52		d n bright floc.
			7		+24	10.0	56		bright floc.
575	July 11	6 52	2	−53		2.4	264	Eu	d a long slim prom.
			8	+ 6		0.4	110	Nu	bright floc.
585	July 12	17 35	5	+ 8		12.0	44		bright floc.
633	July 21	6 52	12	+27		10.0	48	Eu	
640	July 22	7 21	12	+23		18.0	81		n bright floc.
713	Aug. 2	6 42	7	+18		10.0	92		
958	Sept. 3	6 58	5		+51	10.0	44		d
1016	Sept. 10	6 55	1	− 1		2.0	110	Su	
			7	+23		10.0	30		small bright floc.
1033	Sept. 12	9 24	2	−55		5.0	121		d f
	1907								
1827	May 21	6 58	1	−48		0.5	198		f very long slim prom.
1837	May 23	6 43	1	−53		0.3	121		d f
1960	June 10	7 9	3	+57		3.0	116		d
1975	June 13	6 55	4	+ 4		—	132		detached cloud above chromosphere
2006	June 16	7 7	3		−58	11.0	48		d d
			10	−18		13.0	108		bright floc.
2012	June 17	7 16	2		−58	22.0	77		
2027	June 19	6 56	7		+38	10.0	55		
2053	June 23	7 0	2	−60		—	121		d detached clouds
2080	June 26	6 49	2		−33	13.0	48		
2099	June 28	7 13	7		+83	—	143		cloud
2117	June 30	6 55	4		+60	10.0	44		
2145	July 4	6 55	4	+65		12.0	103		d d
			5	+42		11.0	121		small dark floc.
2169	July 7	7 29	1		−16	10.0	29		bright floc.
2184	July 9	7 13	2	−21		2.0	132	Su	d
2193	July 10	6 54	1	−29		3.0	132	Su	cloud projected from top of prom. bright floc. spot.
2208	July 11	6 55	1	−32		3.0	121	Su	f spot, bright floc.
2217	July 12	6 53	1	−34		4.0	143	Eu	f tree-shaped prom. large spot 5° E
			3		−23	10.0	44	Su	
2227	July 13	6 45	1	−14		11.0	35		
			2	−34		10.0	121	Eu	

TABLE I—*Continued*

Plate No.	Date	P.S.T.	No. Prom.	Heliographic Lat. Quadrant		Base	Height	Direction	Remarks
				East	West				
	1907								
2236	July 14	6^h56^m	1	−16°		10.0	66″	Su	bright floc.
2245	July 15	6 57	7		+35°	1.0	110	Wu	f tree-shaped
2255	July 16	7 8	2	−52		1.0	143		d
			4		−31	27.0	77	Wu	n
2264	July 17	6 46	2	−41		2.4	220	Su	form an arch. 2_1 may be the extremity of prom. 2. dark floc. between 2 and 2_1 and prom. is bent in toward it
			2_1	−73		0.5	242	Eu	
			3	−85		1.5	120	Eu	d
			4		−72	1.8	121	Su	d d
			6		−35	1.5	176	Su	n small bright floc.
2284	July 19	6 56	2	−84		0.8	132	E	f
			5		+25	—	176		large cloud
			7	+10		20.0	48		bright floc.
2297	July 20	7 9	2	−76		1.0	132	Su	d long thin prom.
2303	July 21	7 2	1	−15		10.0	55		bright floc.
			4	−84		0.6	132		f tree-shaped
2312	July 22	7 13	3		−85	2.0	132	Su	f
2318	July 23	9 46	2		−84	2.0	121	Su	d
			6	+48		3.0	110	Eu	
2329	July 24	7 32	3		−30	—	143		small clouds d d
2345	July 25	6 53	1		−83	1.0	120	Su	
			2		−30	2.0	121	Su	bright floc.
			4		− 7	10.0	132	Nu	f f
2354	July 26	6 45	1	−12		12.0	66		
			5		−21	0.4	154	Wu	d n bright floc.
2373	July 28	6 54	2		−81	1.3	121	Su	
			10	+19		10.0	55	Eu	f
2383	July 29	6 49	4		−44	6.0	101	Wu	d
			7		+33	10.0	55	Wu	
2393	July 30	7 19	7		+30	18.0	37		
2403	July 31	7 32	2		−80	1.0	121	Su	d one filament
			4		+23	11.0	42		
			6	− 2		12.0	37		bright floc.
2420	Aug. 2	7 11	6		+11	10.0	59		v
2430	Aug. 3	6 47	2	−44		1.3	132		f
2439	Aug. 4	7 6	1	−44		1.0	132	Su	d f
			3		−11	13.0	66		
2457	Aug. 6	6 52	2	−29		1.0	121	Eu	
			13	+ 1		12.0	48		
2476	Aug. 8	7 8	4		−52	4.0	121	Su	
			7	+56		0.6	110		
2495	Aug. 10	6 54	7	−71		2.0	253	Su	d d f; near base
2507	Aug. 12	6 53	1	−43		11.0	60		
			5	+19		25.0	77		bright floc. on Aug. 11

TABLE I—*Continued*

Plate No.	Date	P.S.T.	No. Prom.	Heliographic Lat. Quadrant		Base	Height	Direction	Remarks
				East	West				
	1907								
2516	Aug. 13	6^h50^m	6	$+59°$		15.0	67″		
			7	+26		40.0	99		v v very large prom. small bright floc.
2525	Aug. 14	6 58	2	−43		10.0	48	Eu	
			10	+61		2.5	143		d
			11	+20		17.0	77		v small bright floc.
2534	Aug. 15	6 48	8	+11		20.0	52		
2543	Aug. 16	6 44	1	−14		10.0	44		bright and dark floc.
			5	+38		10.0	77	Eu	
2554	Aug. 17	17 9	1	−11		23.0	60		
			5		$-57°$	2.5	242	Wu	f } form an arch
			6		−47	3.0	220	Su	f }
2560	Aug. 18	6 55	4		−73	1.5	132		d small cloud above prom.
2569	Aug. 19	6 53	1	−36		15.0	34		
			9		+43	—	198		cloud high above chromosphere
2578	Aug. 20	6 45	9		+16	12.0	55		
			10		+58	10.0	88	Wu	
			12	+47		3.0	132	S ‖	f
2587	Aug. 21	6 52	3	−54		13.0	48	Eu	
			9		+52	1.5	165		
2597	Aug. 22	6 52	4	−58		13.0	77	Eu	
2606	Aug. 23	7 0	1	−21		13.0	143		
2619	Aug. 24	6 59	1	−21		—	253	Eu	d cloud high above chromosphere
			2	−59		7.0	120		bright floc.
2629	Aug. 25	7 15	1	−26		12.0	132		bright floc.
2657	Aug. 28	7 10	5		+ 4	20.0	92		bright floc.
2667	Aug. 29	7 24	2	−84		21.0	88		
			5		+10	18.0	81		bright floc.
2685	Aug. 31	7 6	4		−55	37.0	121		d f
2699	Sept. 3	7 2	1	−44		15.0	72	Eu	
2708	Sept. 4	6 54	1	−44		12.0	66		
			3		−19	15.0	59		bright floc.
2718	Sept. 5	7 11	2		−20	4.0	132		d bright floc.
2736	Sept. 7	7 4	4		−14	—	132		d d small cloud above chromosphere. bright floc.
2752	Sept. 9	7 27	6		− 8	1.5	132		
2759	Sept. 10	7 15	4		− 4	0.3	132		f
			7		+57	10.0	103	Wu	
2780	Sept. 13	7 15	5		−47	5.0	132	Wu	
2789	Sept. 14	7 13	2		−39	20.0	126	Su	f
			3		− 6	—	120		d small cloud
2798	Sept. 15	7 20	6	+28		17.0	70		f
2806	Sept. 16	7 16	3		+42	1.3	120		d
2815	Sept. 17	7 7	10	+24		16.0	120		f d

TABLE I—*Continued*

Plate No.	Date	P.S.T.	No. Prom.	Heliographic Lat. Quadrant		Base	Height	Direction	Remarks
				East	West				
	1907								
2824	Sept. 18	7^h16^m	3		−49°	2°.0	132″		d
2851	Sept. 21	7 30	1	−47°		—	121		d d small cloud
2897	Sept. 27	7 11	6		−65	6.0	120		d d
2906	Sept. 28	7 16	6		−59	1.4	121	Su	
2918	Sept. 30	7 19	4		+19	5.0	165	Wu	
2927	Oct. 1	7 15	7		+24	7.0	120	Wu	f
2979	Oct. 10	8 9	1	− 2		14.0	120		d d
			9		−30	20.0	103		
2988	Oct. 11	7 50	1	−40		13.0	41		v
			7		−37	4.4	176	Su	
			8		−30	1.3	100	Su	
3043	Oct. 20	7 44	7	+67		6.0	120		
3059	Oct. 29	8 5	1	+ 4		8.0	121		
			9		+33	11.0	87		d
3084	Nov. 2	8 17	4	−82		1.0	120	Eu	f
			6		+23	11.4	35		
3102	Nov. 4	8 59	5	+35		—	120		d cloud above chromosphere
3208	Nov. 22	8 7	5		+ 7	0.4	110		f
			6		+ 9	0.4	110	Wu	f bright floc. spot
3258	Nov. 30	8 27	2	−34		14.0	44		bright floc.
			7		−28	13.0	60		
3386	Dec. 27	10 26	1	−43		3.0	143	S dw	f
	1908								
3504	Feb. 4	8 40	2		−46	—	132		cloud
3519	Feb. 7	8 41	1		−52	11.0	100		
3646	Mar. 11	8 12	6	−15		3.4	110		f
3745	Mar. 24	8 3	2		+46	1.0	136	Wu	
3763	Mar. 28	10 8	2		+ 4	10.0	66		f

TABLE II

HYDROGEN (*Hα*) PROMINENCES

Height ≷ 100″, or Base ≷ 10°

PLATE NO.	DATE	P.S.T.	NO. PROM.	HELIOGRAPHIC LAT. QUADRANT		BASE	HEIGHT	DIRECTION	REMARKS
				East	West				
	1908								
4019	May 5	8^h16^m	1		−31°	11.°0	55″		
4069	May 16	8 11	4	−20°		18.0	76		
4084	May 17	17 29	2	−18		12.0	77		f f dark floc. on *Hα* plate
4292	June 12	17 58	2		+ 7	10.0	42		bright floc.
4485	July 1	6 55	1		−41	11.0	66	Su	
4534	July 5	17 43	2		+ 1	10.0	66		spot. bright floc.
4702	July 26	7 12	3		+34	5.0	108		
4925	Aug. 27	6 40	2		− 4	10.0	30		bright floc.
4944	Aug. 29	6 44	5		− 2	16.0	77		bright floc.
5009	Sept. 4	7 12	6		−15	—	132		d d cloud above chromosphere. spot
5021	Sept. 5	7 35	1	−9		13.0	44		
5036	Sept. 8	7 17	3		+33	10.0	59	W ‖	n
5115	Sept. 18	7 26	1	−21		2.8	110		d d n
5238	Oct. 7	7 19	3	−56		6.4	110		
5267	Oct. 10	7 45	3		−38	1.8	102		cloud detached from upper part of chromosphere
5358	Oct. 28	7 26	7		+14	10.0	42		bright floc.
5380	Oct. 31	7 15	3		−34	10.0	57	W ‖	cloud detached from upper part of prom.
5420	Nov. 9	7 49	5	+13		24.0	88		
5426	Nov. 10	7 26	1	+ 5		25.0	88		
5456	Nov. 17	7 43	3		−32	10.0	57		
5461	Nov. 18	7 43	5		+14	1.0	136		f bright floc.
5477	Nov. 23	7 46	1	−11		—	100		large detached cloud above chromosphere
5491	Nov. 30	8 2	5		+35	2.6	154		
5494	Dec. 7	7 58	2		−20	4.0	143		small bright floc.
	1909								
5657	Feb. 26	8 37	1	−10		15.0	56		d
5661	Feb. 27	8 19	5	− 7		20.0	62		f
5666	Feb. 28	8 39	4	− 3		16.0	54		
5703	Mar. 14	8 40	2		+11	15.0	60		small bright floc.
5722	April 1	9 0	2		+17	5.0	37		bright floc.

TABLE III

COMPARISON OF PROMINENCES OBSERVED AT MOUNT WILSON AND WILLIAMS BAY

Mount Wilson							Williams Bay*						
Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad. East	Hel. Lat. and Quad. West	Base	Height	Direction	Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad. East	Hel. Lat. and Quad. West	Base	Height	Direction
		Calcium (H) Prominences							Calcium (H) Prominences				
1906	1	+71°		1°	67″	Eu	1906	1	+72°		2°	85″	N dw
	2	+ 5		1	56		2038						
500	3	−22		6	34		June 30	2	−69		4	53	
June 30							17h44m	3		−78°	—	64	
14h50m	4		−53°	2	22			4		−54	1	32	
	5		+ 8	6	22								
	1	−34		2	67	Su		1	−54		7	42	
	2	−54		3	90	Eu		2		−60	1	32	Wu
	3		−60	2	22	Wu	2047	3		−62	1	21	Su
575	4		−63	1	34		July 11						
July 11	5		−19	3	56		21h53m	4		+20	6	32	
14h52m	6		+ 5	7	56			5		+50	2	32	
	7		+50	6	56								
	8	+ 4		1	90	N ||						
	1	−55		5	45								
	3		−62	1	34								
	31		−60	1	34								
578	4		−11	2	22								
July 12	5		− 3	2	45								
1h48m	6		+ 3	4	56								
	7		+18	3	34								
	8		+50	3	67								
	1	−48		1	168	f							
1907	2	−67		2	67	Eu	1907	1	−71		10.0	244	Eu
1827							2281	2	−77		2	74	
May 21	3		−86	3	34		May 21	3		−84	2	42	
14h58m	4		−43	3	45		16h52m	4		−44	4	53	S dw
	5	−30		1	45								
	1	−64		3	45			1	−62		1	32	
								2	−66		3	53	
								3	−72		1	42	
								4		−46	5	42	
	2		−27	1	34	Wu		5		−25	2	42	
1879	3		−20	2	34		2288	6		−18	2	42	S ||
May 28	4		−13	6	78		May 28						
15h24m	5		− 6	2	34		16h12m	7		− 5	2	74	
	6		− 1	4	34			8		+31	4	42	
	7		+39	3	56								
	8		+41	2	34								
	9	+34						9	+33		3	32	

* It should be stated that these plates taken at Williams Bay are not suitable for a statistical comparison of this sort, because the diameter of the solar image is so nearly equal to the width of the plate that prominences near the east and west limbs generally do not make a sufficient impression. To cover these portions of the sun two exposures are necessary, with the limbs successively set nearer the center of the plate. Unfortunately, in the plates compared here, this procedure had not been followed, as no such comparison was contemplated.

TABLE III—*Continued*

Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad. East	Hel. Lat. and Quad. West	Base	Height	Direction
MOUNT WILSON						
Calcium (H) Prominences						
1907	1	−11°		8°	45″	
	2	−41		2	112	S ‖
	3	−70		2	157	E ‖
2264	4	−84		1	22	
July 17						
14^h47^m	5		−60°	1	34	
	6		−37	2	168	Su
	7		+ 1	8	34	
	8	+38		2	34	
	1	−13		1	67	Eu
	2	−20		4	67	Eu
	3	−34		4	22	
2495	4	−42		6	90	
Aug. 10	5	−51		5	56	
14^h54^m	6	−72		—	235	d
	7	−88		2	45	
	8		+53	4	34	
	9	+53		3	34	
	1	−23		3	22	
	2	−43		6	45	Eu
2525	3	−79		1	55	
Aug. 14	4		−32	5	45	
14^h58^m	5		+ 7	0.5	90	Wu
	6	+19		14	67	
	7	+61		2	143	
	1	−20		15	146	E ‖
2606	2	−55		12	90	
Aug. 23	3	−77		6	67	
15^h0^m	4		−74	3	45	
	5	+56		2	45	
	1	−38		5	56	
	2	−51		4	34	
2780	3	−78		3	67	d
Sept. 13	4		−46	5	123	W ‖
15^h15^m	5		−38	7	67	W ‖
	6		+11	0.5	33	
	7		+21	3	34	N ‖
	8		+27	2	34	N ‖
Hydrogen (*Hα*) Prominences						
1908	1	+62		2	44	
3925						
April 20	2	−17		2	34	
15^h57^m	3	−25		6	34	

Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad. East	Hel. Lat. and Quad. West	Base	Height	Direction
WILLIAMS BAY						
Calcium (H) Prominences						
1907	1	− 7°		3°	32″	S ‖
	2	−82		4	106	
2390	3		−73°	1	64	
July 17	4		−61	14	201	W ‖
17^h56^m	5	+40		1	21	
	1	−14		2	42	Eu
	2	−23		4	64	Eu
	3	−37		5	32	
2443	4	−44		6	85	Su f
Aug. 10	5	−54		4	53	
15^h1^m	6	−74		—	170	d
	7	−84		3	95	d d
	8		+53	4	32	
	9	+51		3	32	
	1	−31		3	85	E dw
	2	−45		8	42	f
2463	3	−81		2	42	
Aug. 14						
17^h36^m	4	+59		—	127	
	1	−22		9	64	E ‖
2479	2	−56		11	74	S dw
Aug. 23	3	−80		6	64	
15^h54^m	4	−74		1	32	
	1	−33		5	64	
	2	−43		6	32	
	3	−56		2	32	
	4	−77		1	53	
2507	5	−81		2	21	
Sept. 13						
16^h54^m	6		+ 8	7	53	
	7		+21	2	42	N ‖
	8		+28	2	32	N ‖
	9	− 5		4	21	
Calcium (H) Prominences						
1908	1	+60		8	42	
2684	2	+22		1	32	
April 20						
16^h34^m	3	−85		—	64	d d

TABLE III—*Continued*

Mount Wilson							Williams Bay						
Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad. East	Hel. Lat. and Quad. West	Base	Height	Direction	Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad. East	Hel. Lat. and Quad. West	Base	Height	Direction
Hydrogen ($H\alpha$) Prominences							Calcium (H) Prominences						
1908							1908						
	1		+ 4°	2°	56″								
4233	2		+ 8	3	45	d d							
June 6	3		+11	1	22								
16^h5^m	4		+20	2	56								
	5		+27	1	22								
							2736	1	−43°		3°	32″	
							June 6	2		−45°	2	21	
							16^h44^m	3		−34	1	21	
	1	−51°		3	34		2741	1	−55		4	42	
4292	2		+ 6	7	34	E dw	June 12						
June 13	3	+56		2	22		15^h55^m	2	+55		3	21	
1^h58^m	4	−22		4	45	Nu							
								1		−22	5	32	
4437	1		−26	1	22		2783	2		+27	3	42	
June 26	2		+27	2	45		June 26	3		+52	3	21	
15^h11^m	3		+51	2	22		15^h43^m	4		−55	—	117	
	1	−25		2	34			1	−28		2	21	
	2	−40		2	56								
								2	−45		5	74	E ‖
	3	−58		3	34			3	−61		5	95	E ‖
4594	4		−71	1	34		2827						
July 14							July 14	4		−65		85	
14^h46^m	5		−21	3	22		16^h36^m						
	6		+17	3	34			5		+19	4	53	
	7	+53		2	34			6	+52		2	21	
	8	+ 1		5	56	Nu		7	+ 1		2	32	
	9	− 4		4	—								
								8	−14		5	32	
	1	−27		2	34			1	−29		2	42	S ‖
4601								2	−52		1	53	Eu
July 15							2838	3		−39	1	64	
14^h35^m							July 15	4		−35	2	64	
	2	+ 1		1	45								
	3	−11		1	22			5	−13		2	42	
	1	−20		2	22								
4667	2		−67	1	45			1		−66	6	85	W ‖
July 22	3		−60	1	34			2		−59	1	64	S ‖
14^h45^m	4		−35	2	78		2847	3		−31	2	95	Wu
							July 22	4		+59	1	32	
							15^h56^m	5	−48		—	64	
								6		−76	3	42	W ‖
	1		−59	1	22			1		−61	3	95	
								2		−57	2	148	
	2		−31	3	45		2875	3		−31	4	53	
4719	3		+38	2	22		July 28	4		+38	4	53	
July 28	4		+40	2	34		15^h22^m	5		+42	2	42	
14^h54^m	5		+53	1	34			6		+53	5	42	
	6		+56	2	45								
	7	+21		4	22								

TABLE III—*Continued*

Mount Wilson							Williams Bay						
Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad.		Base	Height	Direction	Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad.		Base	Height	Direction
		East	West						East	West			
Hydrogen (*Ha*) Prominences							Calcium (H) Prominences						
1908							1908						
	1		−31°	5°	34″			1		−61°	3°	95″	
	2		−25	2	56			2		−56	2	148	
	3		−16	3	22		2879	3		−30	4	53	
	4		+39	3	22		July 28	4		−38	5	42	
4729	5		+54	7	45		15^h58^m	5		+42	2	42	d d
July 29	6	+32°		1	22			6		+54	5	42	
15^h42^m	7	+28		1	34			1		−29	4	32	
	8	+17		1	22		2883	2		−22	2	74	W ‖
	9	+11		1	56		July 29	3		−15	2	32	
4747	1	−50		8	101		17^h14^m	4		+40	4	42	
Aug. 5	2		+34	2	34			5		+54	7	42	
2^h3^m	3	+45		2	34								
	1	−30		3	22								
	2		− 5	2	45			1	−53°		8	95	
4776	3		− 2	2	22		2914	2		+34	4	21	
Aug. 8	4		+25	3	34		Aug. 4	3	+45		3	32	
14^h40^m	5		+29	2	45		20^h56^m	4	−35		1	32	
	6		+34	3	56			1	−32		3	32	
	7	+53		2	45			2	−57		2	32	
	1	−48		2	67					− 4	2	32	
	2	−53		2	67		2938						
	3	−57		1	45		Aug. 8	3		+26	5	42	
	4		−41	1	34		16^h8^m	4		+34	2	53	W ‖
4811								5	+55		7	42	
Aug. 13	5		−25	2	22			1	−48		5	95	E ‖
14^h51^m								2	−54		3	95	E ‖
	6		+34	2	22			3	−59		2	53	
	7		+39	3	34			4		−40	1	42	
	8	+56		3	45			5		−33	5	32	
	9	+52		1	34		2947						
	10	+18		2	34	Eu	Aug. 13	6		+24	5	32	
							15^h42^m	7		+35	5	117	N dw
	1	−52		4	34			8	+55		3	32	
	2	−56		0.5	45								
	3	−60		0.5	22			9	−36		1	32	
4819	4		−38	1	45	Su	2956	1	−56		7	64	
Aug. 14	5		−35	1	34	S ‖	Aug. 14	2	−62		1	53	
14^h54^m	6		−21	2	34		17^h56^m	3		−35	3	42	d d
	7		+25	1	34								
	8		+36	3	45								

TABLE III—*Continued*

Mount Wilson							Williams Bay						
Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad. East	Hel. Lat. and Quad. West	Base	Height	Direction	Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad. East	Hel. Lat. and Quad. West	Base	Height	Direction
Hydrogen (*Hα*) Prominences							**Calcium (H) Prominences**						
1908							1908						
	1		−57°	2°	34″			1		−54°	2°	32″	
4881	2		−31	2	78	Su	2970	2		−50	3	32	
Aug. 21	3		+12	—	45		Aug. 21						
15h0m	4		+46	4	56		17h14m	3		+48	4	64	
	5	+22°		1	34								
	1	−10		3	34			1	−11°		2	21	
	2	−19		2	34		2974	2	−20		1	21	
4890	3		−63	2	22		Aug. 22	3		−61	2	21	
Aug. 22							15h44m	4		+36	1	53	W ‖
15h1m	4		+48	6	67			5		+48	6	74	
	5	+17		6	34								
	6	+10		2	34								
	1	−29		8	34			1	−31		8	21	
	2		− 4	9	34		2990	2		− 4	10	42	d
4925	3		+28	7	22		Aug. 27						
Aug. 27							16h5m	3		+20	10	85	d d
14h40m	4	+12		4	22								
	5	+ 4		2	22								
	1	−19		1	22	d		1	−20		1	21	
	2	−32		0.5	45	d		2	−33		1	53	
4944	3	−39		2	67	d	3006	3	−39		2	85	Su
Aug. 29	4		−55	2	34		Aug. 29	4		−54	2	32	
14h44m	5		− 1	11	67		15h36m						
	6		+28	2	56			5		+28	2	64	
	7		+44	1	22								
	1	− 3		2	22			1	− 2		4	21	
	2	−12		3	22								
	3	−25		2	34	Su		2	−25		1	32	S ‖
4985	4		− 7	9	101		3036						
Sept. 2	5		− 3	1	45		Sept. 2						
15h16m	6		+13	1	45		16h37m	3		+15	1	42	
	7		+17	1	34								
	8		+42	1	45			4		+42	1	53	W ‖
	9	+48		1	34			5	+47		2	32	
	1	−27		1	34			1	−29		1	32	
	2		− 5	—	56								
4998	3		+18	9	74		3042	2		+14	1	78	N dw
Sept. 3							Sept. 3	3		+29	2	42	
15h22m	4	+63		2	22		17h37m	4	+61		0.5	21	
	5	+52		3	56	E ‖		5	+52		1	74	Eu
	6	+46		1	56	N ‖		6	+45		1	32	
	1	− 9		4	34			1	− 9		7	21	
	2	−14		1	34								
5009	3	−20		2	22		3047						
Sept. 4	4	−29		0.5	11		Sept. 4						
15h12m	5		+ 6	2	22		17h44m	2		+ 6	4	32	
	6		+10	1	34								
	7		+17	4	34			3		+16	4	32	

TABLE III—*Continued*

Mount Wilson							Williams Bay						
Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad. East	Hel. Lat. and Quad. West	Base	Height	Direction	Plate No., Date, and G.M.T.	No. of Prom.	Hel. Lat. and Quad. East	Hel. Lat. and Quad. West	Base	Height	Direction
Hydrogen (*Hα*) Prominences							Calcium (H) Prominences						
1908							1908						
5036	1	−53°		1°	22″			1	−53°		4°	32″	d d
Sept. 8	2		−29°	6	42		3060						
15^h17^m	3		+34	7	64	W ‖	Sept. 8	2		+32°	3	42	W ‖
							17^h9^m	3		+37	4	74	W ‖
	1	−50		2	42			4	−33		2	21	
5199	2		−14	2	42	W ‖		1	−51		3	42	
Oct. 1	3		+ 4	1	21	N ‖	3138						
15^h14^m	4		+17	5	21		Oct. 1	2		+ 6	2	42	
	5		+38	3	42		15^h43^m	3		+19	7	32	
	1	+ 1		3	42			4		+40	5	42	
	2	−33		4	64	E ‖		1	− 1		2	42	
5238	3	−56		7	95	Su f		2	−36		4	64	E dw
Oct. 7	4		−26	8	32		3160	3	−57		8	148	Su
15^h19^m	5		+29	3	64	Nu	Oct. 7						
	6		+34	2	42		17^h55^m	4		+30	1	95	
	7	+38		1	21			5		+35	2	42	
	1	−29		1	32			1	−29		1	32	
	2	−71		3	21			2	−70		5	32	
5267							3172	3		−53	3	21	
Oct. 10	3		−39	2	22	Su	Oct. 10						
15^h45^m	4		−14	2	22	S ‖	16^h10^m						
	5		− 6	1	21			4		− 7	1	42	
								5	+ 3		1	32	
	1	− 4		3	32			1	− 5		3	53	
	2	−17		4	32		3205	2	−18		3	42	
5420	3		−49	2	85	Su	Nov. 9						
Nov. 9	4		−44	1	42		16^h49^m						
15^h49^m								3		+40	2	21	
	5	+11		>12	74								

REMARKS

Mount Wilson

1879 (2)–(6) big prominence covering almost all the space between −27 W and +1 W.

2264 between (2) and (3) big arch. (6) big cloud almost detached from chromosphere.

Williams Bay

2038 (3) small cloud detached from chromosphere.

2281 (1) big ring. *Astroph. Journ.*, **26**, 155, 1907

2288 (5)–(7) big prominence covering all the space between −25 W and −4 W.

2390 (4) beautiful prom. extending very far toward W.

REMARKS—*Continued*

Mount Wilson		Williams Bay	
2495	(6) big cloud floating above chromosphere.	2443	(6) cloud detached from chromosphere: from a later plate the cloud seems to fall on the chromosphere.
2525	(5) d. thin filament.		(7) high cloud detached from chromosphere.
2606	(1) big mass compact.	2463	(1) f. prom. falling on the chromosphere over a low prom.
			(4) thin filament floating above chromosphere.
		2479	(1) very d toward E.
		2507	from (1) to (3) in connection.
4233	(1) thin at base like a detached cloud floating above chromosphere.	2684	(3) detached from chromosphere.
		2783	(4) arrow-shaped prom. detached from chromosphere.
4594	(4) a small detached cloud.	2827	(2) and (3) d. cloud hanging over the chromosphere between prom. (2) and (3).
			(4) small prom. hanging over the chromosphere.
4881	(3) small cloud detached from chromosphere.	2827	(7) and (8) one hour later on plate 2828. prom. (7) is 117″ high and (8) is 42″ high.
4985	(4) big cloud floating above chromosphere. (8) detached from chromosphere.	2847	connection between (1), (2), and (6).
4998	(2) detached from chromosphere.		(6) toward (1); (1) toward (2);
	(5) and (6): (5) is bent toward (6) and (6) toward (5).		(2) toward (1).
		2883	long thin stream going W.
5009	(6) in connection with (7).	2947	(1) almost going to touch (9).
5199	(2) small cloud suspended toward W.		(7) big mass going up and falling on the chromosphere at +45 W.
5238	(2) extending to −29 E toward East.	3006	(4) small arch.
5267	(3) very faint cloud going toward S.	3160	(2) long arm extending downward to −25°.
			(4) almost detached from chromosphere.

We desire to express our appreciation of the kindness of Mr. Ellerman and of Mr. Fox, which enabled us to make the above measures.

Mount Wilson Solar Observatory
December 1910

PHOTOGRAPHIC DETERMINATIONS OF STELLAR PARALLAX MADE WITH THE YERKES REFRACTOR. III

By FRANK SCHLESINGER

THE METHOD OF REDUCTION

Before we can compare one plate with another, and so derive the shifts due to parallax and proper motion, it is necessary to clear the measures of certain other causes of difference. These may be classified into two groups, the first of which comprises *orientation*, *scale*, and *zero* corrections; the second, *refraction*, *aberration*, *precession*, and *nutation*. Those in the first group are to be determined from the measures themselves, and, under these circumstances, as is well known, we need pay no attention to those in the second group. The reason for this is that the correction for scale (a) of the co-ordinate X, is of the form $a \cdot X$; that for orientation (b) is proportionate to the other co-ordinate Y, and takes the form $b \cdot Y$; while the zero correction (c) is applied as a constant to all the measures. The sum of the three is $a \cdot X + b \cdot Y + c$. It is obvious that this is also the form assumed by any correction whatever that we may take to be linear over the narrow area covered by a plate; consequently, as Turner first pointed out, any such correction is automatically applied when we determine the scale, etc., from the measures themselves. The more rigorous expressions for the corrections in the second group contain terms in X^2, Y^2, and $X \cdot Y$, not to mention those of still higher order; but all of these are inappreciable on these plates, the distance from the parallax star to any comparison star never exceeding half a degree.

For those cases in which both co-ordinates have been measured, the two have been reduced without reference to each other in order that the derived parallaxes may be entirely independent. Had we combined the two sets into one solution, it would have been necessary to apply corrections for refraction, and to employ Jacoby's method. This additional work is justified if the parallax star is far removed from the mean position of the comparison stars.

In reducing all the plates to the same scale, etc., it makes no practical difference which of them is assumed to be the standard. The truth of this statement is tolerably obvious and a rigorous proof is easily adduced. Having then chosen one of the plates for this purpose, or the mean of several, the usual method is to deduce a, b, and c from a least-squares solution. The observation equations, of which there will be one for each of the n comparison stars, take this form:[1]

$$\left.\begin{aligned} a\cdot X_1+b\cdot Y_1+c+(X'_1-X_1)&=v_1\\ a\cdot X_2+b\cdot Y_2+c+(X'_2-X_2)&=v_2\\ &\text{etc.}\end{aligned}\right\} \quad (1)$$

Here X_1, X_2 refer to the standard plate and X'_1, X'_2 to the plate that we are reducing. The analytical expressions will be simplified if we suppose that a certain constant has been subtracted from the co-ordinates on the standard plate, so as to make $[X]$ and $[Y]$ each equal to zero. The normal equations are then as follows:

$$\left.\begin{aligned} [X^2]a+[X\cdot Y]b &= -[X(X'-X)]\\ +[Y^2]b &= -[Y(X'-X)]\\ +n\cdot c &= -[X'-X]=-[X']\end{aligned}\right\} \quad (2)$$

Whence

$$\left.\begin{aligned} a&=\frac{[Y(X'-X)][X\cdot Y]-[X(X'-X)][Y^2]}{[X^2][Y^2]-[X\cdot Y]^2}=\\ &\qquad 1-\frac{[X\cdot X'][Y^2]-[X'\cdot Y][X\cdot Y]}{[X^2][Y^2]-[X\cdot Y]^2}\\ b&=\frac{[X(X'-X)][X\cdot Y]-[Y(X'-X)][X^2]}{[X^2][Y^2]-[X\cdot Y]^2}=\\ &\qquad \frac{[X\cdot X'][X\cdot Y]-[X'\cdot Y][X^2]}{[X^2][Y^2]-[X\cdot Y]^2}\\ c&=-\frac{1}{n}[X']\end{aligned}\right\} \quad (3)$$

Finally we compute for the parallax star

$$X'_\pi+a\cdot X_\pi+b\cdot Y_\pi+c. \quad (4)$$

This quantity, which we shall designate by m', may be called the solution of this plate. A comparison of the values of m', m'', from various plates enables us to determine the parallax.

[1] We confine our attention for the present to the case in which co-ordinates in only one direction have been measured.

The labor of computing the plate-constants by this method, for as large a number of plates as are included in the present work, is very considerable. The following method is much shorter and leads to precisely the same results.

The plate-constants are of no interest in themselves in the present connection. Their computation may be altogether avoided, and the numerical work much abridged, by expressing m' directly in terms of the observed quantities X'_1, X'_2, etc. To effect this we substitute in (4) the values of a, b, and c as given in equations (3), and then collect the terms in X'_1, those in X'_2, etc.

$$\left.\begin{aligned} m' = {} & X'_\pi + X_\pi \\ & - X'_1 \left\{ \frac{X_1(X_\pi[Y^2]) - Y_1(X_\pi[XY]) + Y_1(Y_\pi[X^2]) - X_1(Y_\pi[XY])}{[X^2][Y^2]-[XY]^2} + \frac{1}{n} \right\} \\ & - X'_2 \left\{ \frac{X_2(X_\pi[Y^2]) - Y_2(X_\pi[XY]) + Y_2(Y_\pi[X^2]) - X_2(Y_\pi[XY])}{[X^2][Y^2]-[XY]^2} + \frac{1}{n} \right\} \\ & - \text{etc.} \end{aligned}\right\} \quad (5)$$

In this notation the comparison stars are distinguished from each other by subscripts. The co-ordinates on the standard plate are distinguished from those upon others by the omission of the primes. It will be noticed that the quantities in parentheses are the same for all the comparison stars, and those in the curved brackets the same for all the plates. It will be convenient to have a name for these coefficients in curved brackets; as they show the dependence of the solution (m) upon the comparison stars, we shall call them *dependences* and shall designate them by D_1, D_2, etc. In comparing the values of m from different plates we are at liberty to add a constant to them all, and we may accordingly omit the term X_π that appears outside the brackets in equation (5). This leaves the very simple expression,

$$m' = X'_\pi - [D \cdot X'] \quad (6)$$

Similarly for any other plate $m'' = X''_\pi - [D \cdot X'']$.

The following is a simple numerical example. It relates to the double star *Positiones Mediae 2164* ($18^h\ 42^m, +59^\circ\ 29'$) which is one of those that were measured in right ascension and declination.

Standard Plate		Plate 664 1st Exposure	2d Exposure
$X_1=-378$	$Y_1=+62$	$X'_1=198.766$	$X''_1=175.999$
$X_2=-8$	$Y_2=+200$	$X'_2=569.351$	$X''_2=546.657$
$X_3=+84$	$Y_3=-130$	$X'_3=660.934$	$X''_3=638.083$
$X_4=+302$	$Y_4=-132$	$X'_4=879.485$	$X''_4=856.622$
$X_*=-40.3$	$Y_*=+75.5$	$X'_*=535.133$	$X''_*=512.404$

From the co-ordinates on the standard plate we have

$$[X^2]=241{,}208, \qquad [Y^2]=78{,}168, \qquad [XY]=-75{,}820.$$

Substituting in (5), we obtain

$$D_1=+.000196X_1+.00116Y_1+0.250=0.248$$
$$D_2=+.000196X_2+.00116Y_2+0.250=0.480$$
$$D_3=+.000196X_3+.00116Y_3+0.250=0.115$$
$$D_4=+.000196X_4+.00116Y_4+0.250=0.156$$

These results may be controlled by the equations

$$[D]=1, \qquad [D\cdot X]=X_*, \qquad [D\cdot Y]=Y_* \qquad (7)$$

We have computed these dependences to three decimal places. This is more than ample, and we may if we wish round them off to two decimals. In that case the second and the third control equations will not be so closely satisfied, but this is of no consequence *so long as the orientation and the scale of all the plates to be compared are approximately the same.* The first control should be exactly satisfied by whatever dependences are adopted. In the present example we may take

$$D_1=0.25, \quad D_2=0.48, \quad D_3=0.11, \quad D_4=0.16.$$

The work up to this point is done once for all. We now proceed to reduce the separate plates, or rather the separate exposures; for the numerical work that this method involves is so slight, that it requires hardly more time to treat the exposures separately than to take the means for the three sets of measures on each plate, and then to reduce these means as a whole. The advantages of separate reduction are obvious.

Applying the dependences to Plate 664, for which the measurements of the first and the second exposures are given above, we obtain,

$$m'=-1.267, \qquad m''=-1.239, \qquad m'''=-1.243.$$

It is the mean of these three that appears under the column *m* in the tables of results to be given later.

The dependences not only abridge the computations but they have several other useful applications. They furnish an exact criterion for the *importance* of a comparison star. In the present example we see that as the dependence for the second comparison star is from two to four times that for the others, any inaccuracy in the measurement of this star has a correspondingly greater effect upon *m;* for this reason we measured it twice and the other comparison stars only once. An example of the opposite kind is presented by *60 Krüger* ($22^h\ 24^m$, $+57°\ 12'$), details for which will appear later. The five stars most suitable for the purpose gave dependences of +0.299, +0.057, +0.286, +0.017, and +0.340. The fourth of these is so small that any error in the measurement of the corresponding comparison star would affect *m* very little indeed. It is therefore not worth while to measure this star at all, and it was accordingly dropped. The other dependences then become +0.289, +0.076, +0.289, and +0.345.

It has often been stated that a differential method like the present yields a relative parallax for the parallax star that is less than its absolute value by the *mean* of the parallaxes of the comparison stars. But this is at best a rough statement that applies only if the parallax star is close to the mean position of the comparison stars. The true difference would always be obtained by multiplying the parallax of each of the comparison stars by its dependence and taking the sum. In certain rather extreme cases one of the dependences may come out negative; and then, if the parallax of the corresponding comparison star were unusually large, we should have the curious result that the deduced parallax is *greater* than its absolute value. An example of this case is afforded by *Lalande 23917* ($12^h\ 45^m$, $+1°\ 45'$), one of the stars in the present list. The adopted dependences for the four comparison stars are +0.33, +0.52, −0.30, and +0.45. If the parallax of the third star were greater than $0''.022$, while those of the others were all $0''.005$, then the parallax here deduced for *Lalande 23917* is greater than the absolute parallax. But in this case, as in every other, the *most probable* value of the absolute parallax is obtained

by adding the theoretical parallax corresponding to the mean magnitude of the comparison stars.

Earlier in these papers I stated that guiding error would be largely eliminated if the magnitude of the parallax star were reduced to the mean of the comparison stars. The more exact condition is equality with the sum of the products formed by multiplying the dependence of each star by its magnitude.

If we let E represent the purely accidental error in the measurement of a star (bisection error, distortion of the film, uncertainties in instrumental corrections, etc.), and E_m a similar quantity for m, then we have from equation (6),

$$E^2_m = E^2 + [D^2]E^2 \tag{9}$$

This expression should be borne in mind in selecting comparison stars; other things being equal, preference should be given to that set for which the sum of the squares of the dependences is the smallest. But too much stress should not be laid upon this condition to the neglect of others. Stars near the edges of the plate should be avoided, and all the comparison stars should be of nearly the same brightness, for then the length of exposure can be adjusted to give the best intensity to all, and further, the guiding error will probably be more perfectly eliminated under such conditions.

Equation (9) also indicates that to guard against accidental errors only a few comparison stars need be used. From this point of view, four well-distributed stars are practically as good as forty, especially when we consider that other than purely accidental effects tend to swell the total plate error. From another point of view, a somewhat greater number is desirable: to obtain the absolute parallax we add the mean parallax of stars as bright as the comparison stars. In the present work this correction averages 0".005. The more comparison stars employed, the more confident may we be that this correction is close to the truth in any particular case. I therefore aimed to get five or six good comparison stars in each field; but in seven cases only four were available, and in five others I had to be content with three, the minimum that will suffice. The area of these plates corresponds to less than half a square degree, or only about one-ninth of that

for the Astrographic Catalogue plates. As a consequence it is not always practicable without prolonging the exposures unduly, to obtain as many comparison stars as one could wish. For some objects even three comparison stars are not at hand, and their parallaxes cannot be determined to advantage with this instrument. The field of good definition of the 40-inch objective would probably cover a considerably greater area than that of the plates employed, and this disadvantage might therefore be obviated by the use of larger plates, with of course a larger plate-carrier at the telescope and a larger measuring engine.

Under some conditions the computer may wish to derive the residuals for the individual measurements of the comparison stars. The method of effecting the solutions by means of dependences cannot then be employed, as the plate-constants must be known. The computation of the individual residuals enables the observer to detect discrepancies in the measures and the reductions; but much of the same advantage is retained by the separate reduction of each exposure. Those upon the same plate should differ from each other only on account of purely accidental causes. Even when the computer decides not to employ the dependences to effect the solutions, they should nevertheless be computed, since a knowledge of them is indispensable for an intelligent discussion of the measures. The additional labor involved in deriving the dependences is a matter of perhaps fifteen minutes for each region.

Another method for reducing a plate was earlier employed in this work for preliminary purposes. It is only a trifle shorter than the dependence method and is not based upon the principle of least squares; I therefore abandoned it for even preliminary reductions. But the general process may be of use in applications totally different from the present, and in some of these it may save considerable time; so that I shall take space to describe it briefly.

In the very special case presented by a set of comparison stars whose mean position coincides with that of the parallax star, it is obviously unnecessary to compute the plate-constants. X_π and Y_π are then each equal to zero and we have from (4),

$$m' = X'_\pi - \frac{1}{n}(X'_1 + X'_2 + \text{etc.}).$$

This simplification may be artificially brought about, with any distribution of comparison stars, by *underweighting* some of them so as to make the means of both co-ordinates respectively equal to those for the parallax star. These artificial weights W_1, W_2, etc., may easily be deduced by a graphical process that it would be superfluous to describe here. Having obtained them once for all, the plates are now reduced by simply subtracting the weighted mean of the X-measures upon the comparison stars, from the X-measure upon the parallax star.

This procedure strikes one at first sight as being unduly arbitrary, but it is really no more so than the selection of comparison stars. We are at liberty to use or reject any particular star for this purpose—there can therefore be no objection to our pursuing a middle course and assigning to it half-weight. The only objection to the method is that it is not carried out in accordance with the principle of least squares. This suggests the idea that as the artificial weights may be assigned in an infinite number of ways that conform to the conditions,[1] one of these must correspond to the method of least squares; namely, that one for which

$$\frac{[W^2]}{[W]^2} \text{ is a minimum.}$$

It can be shown that then

$$\frac{W_1}{[W]}=D_1, \quad \frac{W_2}{[W]}=D_2, \text{ etc.}$$

Or, otherwise expressed, the method of artificial weighting becomes identical with the rigorous dependence method. This is in fact the train of thought by which I was led up to the latter, and it was only afterward that I saw that the dependences could be derived in the simpler way already indicated.

Thus far we have referred only to the case in which the displacements in one direction have been measured. If both co-ordinates have been measured, *and if they are to be treated separately*, the same dependences apply to both. That is, letting l' represent the solution in the Y direction,

$$l'=Y'_\pi-(D_1\cdot Y'_1+D_2\cdot Y'_2+ \text{ etc.}) \qquad (10)$$

[1] Providing of course that there are more than three comparison stars.

There remains the case in which the two co-ordinates are to be combined into one solution after the application of refraction corrections. We shall set down the formulae that are then appropriate, although there is no example of this case in the present work. Let A_1, A_2, etc., be the dependences of the solution in the X-direction upon the X-measures; and B_1, B_2, etc., the dependences of the same solution upon the Y's. Then

$$\left.\begin{aligned} A_1 &= \frac{X_\pi \cdot X_1 + Y_\pi \cdot Y_1}{[X^2+Y^2]} + \frac{1}{n} \\ A_2 &= \frac{X_\pi \cdot X_2 + Y_\pi \cdot Y_2}{[X^2+Y^2]} + \frac{1}{n} \\ &\text{etc.} \end{aligned}\right\} \quad (11)$$

$$\left.\begin{aligned} B_1 &= \frac{X_\pi \cdot Y_1 - Y_\pi \cdot X_1}{[X^2+Y^2]} \\ B_2 &= \frac{X_\pi \cdot Y_2 - Y_\pi \cdot X_2}{[X^2+Y^2]} \\ &\text{etc.} \end{aligned}\right\} \quad (12)$$

$$m' = X_\pi' - (A_1 \cdot X'_1 + A_2 \cdot X'_2 + \text{etc.}) - (B_1 \cdot Y_1 + B_2 \cdot Y_2 + \text{etc.}) \quad (13)$$

If the parallax is to be derived from the Y-displacements as well, the same dependences apply except for some changes of sign:

$$l' = Y_\pi' - (A_1 \cdot Y'_1 + A_2 \cdot Y'_2 + \text{etc.}) + (B_1 \cdot X'_1 + B_2 \cdot X'_2 + \text{etc.}) \quad (14)$$

It has already been mentioned that owing to variations in the atmospheric conditions, plates taken with a telescope of so great a focal length are of very different worth. It was therefore necessary to frame a table from which the weight of each plate could be assigned. In this connection other factors than the appearance of the images had to be considered. A plate that had been measured by two observers is entitled to greater weight than one that had been measured only once. Again, the weight cannot be assumed to be proportionate to the number of exposures that a plate contains, since all the exposures upon the same plate have a tendency (doubtless chiefly because of guiding error) to residuals of the same sign. Our table of weights should therefore be one of triple entry: the quality of the images, the number of exposures, and the number of measurements, whether one or two.

From preliminary discussions of several regions, carried out

with the use of approximate weights, information as to these various points was gathered, and the results are embodied in Table III. This table was used in the definitive reductions of all

TABLE III

PLATE WEIGHTS USED IN THE DEFINITIVE REDUCTIONS

	Two Measurements			One Measurement		
	Good	Fair	Poor	Good	Fair	Poor
One exposure.....	0.5	0.4	0.3	0.4	0.3	0.2
Two exposures.....	0.8	0.6	0.4	0.6	0.5	0.3
Three exposures....	1.0	0.8	0.5	0.9	0.7	0.4

the regions here discussed. The "quality of the images" was assigned while the plate was being measured; and not to split hairs on a matter like this, only three designations were employed: "good," "fair," and "poor." If the images showed marked triangularity or if one of the comparison stars could not be measured, the plate was given smaller weight than appears in the table. In the tables of observations that follow, note is made of any circumstance that affects the value of a plate or of one of the exposures. In the case of a few poor plates the measurements were rejected before the parallaxes had been derived, and therefore without any reference to accordance or non-accordance with other plates of the same region. But no plate was rejected, or its weight reduced, because it showed a large residual. The temptation to break this rule is sometimes very strong, but I have thought it better, particularly for the sake of gathering statistical information that will aid in a continuation of this work, to retain every plate whose rejection was not clearly allowable on a priori grounds.

Table III is of considerable general interest, but I shall not discuss it from this point of view; for it is to be considered only as a second approximation. A third and better approximation may be based upon the definitive residuals, and a discussion of them will be found at the end of these papers.

One other preliminary investigation should be described before proceeding to the detailed results: it relates to the effect of a mal-

adjustment of the plate to the focus of the 40-inch objective. The scale of the plate is obviously affected, but this is of no consequence in reductions like the present, where the scale-correction is determined from the measures themselves. There is, however, another and more serious effect that depends upon the position of a star and upon its magnitude. With an objective as excellent as this one, an image in the optical axis is practically perfect as to symmetry, and there is therefore no apparent change in its position for different positions of the plate with regard to the focal plane. The matter is otherwise for an image that is removed from the optical axis by a considerable arc. The distribution of light is not symmetrical and varies moreover for different sections; that is, for different positions of the plate with reference to the focus. The apparent place of a star will therefore depend to some extent upon the adjustment to focus. It will also depend upon the magnitude of the star; for with a faint object only the nucleus appears upon the developed plate, while with a bright one we get in addition the outlying unsymmetrical aberrations.[1]

To ascertain whether this effect is of appreciable size in the present case we measured (in May 1904) the positions of a number of stars upon plates taken as much as 5 mm out of focus. We found that bright stars were always apparently shifted toward the optical axis, with reference to faint stars in their neighborhood. It made no difference whether the plate had been placed within or without the focal plane—the shift was always in this sense. Numerically, it is roughly equal to 0″.01 for each millimeter that the plate is removed from the focal plane, for a difference of one magnitude, and at a distance of 11′ from the optical axis. There is therefore little to fear from this source of error in the present case, but we have here a warning that the plates must be adjusted to focus with some accuracy, that the comparison stars should not differ in brightness too much among themselves, and that we should try to avoid using a set of comparison stars such that all to the east

[1] This is only one among several reasons why the photographic image of a bright star is larger than that of a fainter; others are: imperfect following, poor seeing, chromatic aberration, atmospheric dispersion, and the purely photographic effect known as "creeping," probably due to reflections within the sensitive film.

of the parallax star are bright, and all to the west faint, or vice versa.

THE RESULTS

In the detailed results that now follow, the designation employed for each object is that adopted by Kapteyn and Weersma in their recent compilation.[1] The right ascension and declination that follow the name are for 1900. The co-ordinates of the comparison stars (and their diameters) are expressed in quarter-millimeters; the positive sign indicates that the longitude or the latitude[2] of the corresponding star is *greater* than the mean for all the comparison stars. From these co-ordinates the "computed dependences" result, and these are then rounded off into the "adopted dependences."

For each object a table of particulars concerning the plates is given. The hour angle appears in hours and tenths, and the sign indicates whether the telescope was east or west of the meridian (at the middle of the exposures), the latter being indicated by the positive sign. The number of usable exposures upon the plate is equal to the number of observers in the next column. Here F denotes Fox; J, Jordan; Su, Sullivan; and S, Schlesinger. Any circumstance that affects the weight to be assigned to a plate is noted under the "Remarks."

There then follows a table giving the results of the measurements and reductions. In the column marked t the time is given in days, the zero being chosen somewhere near the middle date so as to simplify the numerical work. In the last column the residuals have been transformed into arc and multiplied by the square root of the weight.

In some cases (all of which are noted in the tables), one or more of the images of a comparison star could not be measured, either because they were missing altogether or because of defects in the film. If only one of the three images was missing, its place could usually be interpolated with sufficient accuracy from the other two, by applying differences ascertained from the other stars upon

[1] *Publications of the Astronomical Laboratory at Groningen*, No. 24.

[2] In some cases these co-ordinates are referred to the equator instead of the ecliptic.

the plate. If this was done, due regard was always had for the change in orientation in going from one exposure to the next, a change that is especially marked in high declinations. Where two or more of the images of a comparison star were missing it was necessary to go to more trouble; approximate dependences were obtained graphically, the comparison star in question being left out of consideration. The plate was now reduced with these dependences; but the solution thus obtained is not comparable with that from other plates, as a constant difference is involved. To obtain this difference and to apply it to the solution of our defective plate, a few exposures upon other plates were reduced with both sets of dependences. A plate or an exposure that had been treated in this way was given reduced weight. In two or three cases, where the missing comparison star had a large dependence, the plate was not used at all.

Throughout these papers *probable errors* are used exclusively.

Groombridge 34 ($0^h\ 13^m$, $+43°\ 27'$)

This is an 8th-magnitude star with a proper motion of nearly $3''$ per annum. Twelve plates were secured under the circumstances shown in Table 1.

TABLE 1

PLATES OF *Groombridge 34*

No.	Date	Hour Angle	Observers	Quality of Images	Remarks
61.....	1903 Aug. 2	−1.1	Su	Fair	
185.....	Dec. 20	−0.7	S, S	Good	Star (1) lacking
433.....	1904 Aug. 25	−0.4	S, Su, S	Good	
449.....	Sept. 4	−0.3	S, Su, S	Good	
538.....	Nov. 20	−0.2	S, Su, S	Good	
558.....	Dec. 17	−0.5	S, Su, S	Good	
725.....	1905 July 25	0.0	F, Su, F	Poor	
735.....	Aug. 12	−0.6	F, Su, F	Poor	
740.....	Aug. 19	−1.0	F, F, F	Fair	
760.....	Sept. 10	0.0	Su, Su, Su	Good	
853.....	Nov. 12	−0.6	Su, J, Su	Fair	
867.....	Dec. 10	−0.2	Su, J, Su	Poor	

COMPARISON STARS

No.	Diameter	X (longitude)	Y (latitude)	Dependence	
				Computed	Adopted
1	0.50	−344	−218	+.311	+.315
2	0.75	−153	−322	+.100	+.10
6	0.91	+ 29	+149	+.277	+.275
7	0.82	+309	− 13	−.039	−.04
9	0.88	+159	+404	+.351	+.35
Parallax star	1.55	− 70.3	+ 83.6		

The first six plates were measured by Miss Ware and the writer, the last six by Miss Ware alone. If there is any systematic difference between the two observers for this region, it will be almost entirely eliminated from the deduced parallax, as three of the plates measured by both have negative parallax factors, while the other three have positive factors.

TABLE 2

Reductions for *Groombridge 34*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
61	0.055	0.3	+0.974	−471	−.018	−.″03
185	0.244	0.6	−0.889	−331	− 34	−.07
433	1.142	1.0	+0.783	− 82	+ 18	+.05
449	1.156	0.5	+0.661	− 72	+ 13	+.02
538	1.286	1.0	−0.568	+ 5	+ 52	+.14
558	1.261	1.0	−0.872	+ 32	− 18	−.05
725	2.036	0.4	+1.002	+252	− 28	−.05
735	2.116	0.4	+0.906	+270	+ 11	+.02
740	2.114	0.7	+0.845	+277	− 4	−.01
760	2.135	0.9	+0.583	+299	− 19	−.05
853	2.227	0.7	−0.446	+362	− 1	.00
867	2.267	0.4	−0.808	+390	− 3	.00

Each plate furnishes an equation of the form

$$P \cdot \pi + T \cdot \mu + c = m, \text{ weight } p$$

where π is the annual parallax, μ is the proper motion in longitude *in 100 days*, and T is the time factor, equal to one one-hundredth

of the corresponding number of days in the column (t). The resulting normal equations are

$$\begin{aligned} +4.609\pi + 2.011\mu + 0.677c &= +1.860 \\ +48.394 \quad +6.603 \quad &= +21.918 \\ +7.900 \quad &= +11.956 \end{aligned}$$

These yield

$$\begin{aligned} c &= +1.275 \\ \mu &= +0.2750 = +0''.732 \\ \pi &= +0.0962 = +\mathbf{0.256 \pm 0''.019} \end{aligned}$$

Probable error corresponding to unit weight, $\pm 0.0151 = \pm 0''.040$.

The residuals resulting from this solution appear in next to the last column of Table 2.[1] They were checked by means of the control equations,

$$[p \cdot v] = 0, \qquad [p \cdot P \cdot v] = 0, \qquad \text{and } [p \cdot T \cdot v] = 0.$$

Groombridge 34 is accompanied at a distance of 39″ by a faint star (magnitude 10.5) that shares its large proper motion. This star is measurable upon most of the plates and a determination of its parallax with considerable weight is possible. Its distance from *Groombridge 34* being so large, the dependences are appreciably different for the two objects. In the same system of co-ordinates as are given above in connection with the bright star, the position of the companion is

$$X = -55.8, \qquad Y = +83.2.$$

The resulting dependences are

Star (1), +.295; (2), +.10; (6), +.275; (7), −.02; (9), +.35.

Solutions made on this basis appear under column (m) in Table 3. Where the weights in this table differ from the corresponding ones in Table 1, the companion is either too weak for accurate measurement or has not been measured at all for one or two of the exposures.

[1] They are transformed to arc by applying the factor 2.66.

TABLE 3

REDUCTIONS FOR THE COMPANION TO *Groombridge 34*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
61 ..	0.052	0.3	+0.974	−471	−.004	−".01
185 ..	0.259	0.6	−0.889	−331	+ 3	+.01
433 ..	1.129	1.0	+0.783	− 82	+ 14	+.04
449 ..	1.147	0.3	+0.661	− 72	+ 16	+.02
538 ..	1.206	0.7	−0.568	+ 5	− 14	−.03
558 ..	1.256	0.7	−0.872	+ 32	− 8	−.02
725 ..	2.036	0.4	+1.002	+252	− 26	−.04
740 ..	2.102	0.7	+0.845	+277	− 13	−.03
760 ..	2.152	0.9	+0.583	+299	+ 2	+.01
853 ..	2.239	0.7	−0.446	+362	+ 18	+.04

The normal equations are

$$+3.607\pi + 2.479\mu + 0.938c = + 2.234$$
$$+39.261 \quad +3.996 \quad = +16.151$$
$$+6.300 \quad = + 9.156$$

These yield

$$c = +1.263$$
$$\mu = +0.2764 = +0''.734$$
$$\pi = +0.1012 = +0''.269 \pm 0''.011$$

Probable error corresponding to unit weight, $\pm 0.0073 = \pm 0''.019$.

The weight of the parallax from this solution is somewhat less than for *Groombridge 34* itself, but the measurements are so much more accordant that the computed probable error comes out only little more than half that in the former case. Most of the discordance among the residuals for the brighter star is due to Plate 538. A least-squares solution for the brighter star without this plate yields $0''.022$ as the probable error corresponding to unit weight.[1] This is only about half that in the definitive solution first given. But there is no a priori reason for rejecting this plate; the images are good and the six separate values of m (three exposures, each measured by two observers) are accordant. The discrepancy cannot be due to inaccuracies in the measurement of the comparison stars, since these same measurements were used in

[1] This solution gives $+0''.281$ for the parallax.

the solution for the companion, and in this solution Plate 538 not only yields a small residual, but it has the opposite sign from the residual in the solution for *Groombridge 34*. Nor can the trouble be due to distortion of the film, for the images of the companion are close to those of the bright star. The most plausible explanation for this large residual is guiding error: *Groombridge 34* is nearly two magnitudes brighter than the mean of the comparison stars.

The rotating disk might have been used to reduce the light of *Groombridge 34*, but in that case it would not have been possible to measure the companion. The parallax here deduced for the latter is the first that has been published; its close agreement with that for *Groombridge 34* must be regarded as conclusive evidence that the two form a true binary. This might also have been inferred from the community of proper motion, but authorities in double-star astronomy do not always take this point of view. For example, the present pair is not included in Burnham's *General Catalogue of Double Stars*, although it is a system of unusual interest. So far as I am aware, the separation of this pair (39″) is greater than for any other known with certainty to be a binary. There are, however, a few of wider separation whose binary character may be inferred from considerations of proper motion.

Combining in accordance with their probable errors the two values that we have derived for *Groombridge 34* and its companion, we have as the definitive parallax of the system,

$$\pi = +0''.266 \pm 0''.010.$$

Other determinations of the parallax of the brighter component are as follows:

Auwers (equatorial transits)	+0″.29	±0.024
Flint (transit circle)	+0.31	.034
Russell (photography)	+0.25	.012
Chase (heliometer)	+0.31	.010

μ Cassiopeiae ($1^h\ 2^m$, $+54°\ 26'$)

This is a 5th-magnitude star of very large proper motion—nearly 4″ per annum. Nine plates were secured as described in Table 1.

TABLE 1

PLATES OF μ *Cassiopeiae*

No.	Date	Hour Angle	Observers	Quality of Images
418	1904 Aug. 7	-0^h5	S, Su, S	Good
421	Aug. 13	−0.6	S, S	Good
426	Aug. 14	−0.6	S, Su,	Good
539	Nov. 20	−0.3	S, Su, S	Good
559	Dec. 17	−0.4	Su, Su, Su	Good
741	1905 Aug. 19	−1.1	Su, Su, Su	Good
770	Sept. 12	−0.6	Su, Su	Fair
778	Sept. 19	−1.8	Su, Su, Su	Fair
886	Dec. 31	−0.2	Su, J, Su	Good

COMPARISON STARS

No.	DIAMETER	*X* (longitude)	*Y* (latitude)	DEPENDENCE	
				Computed	Adopted
3	0.55	−266	+160	+.197	+.20
4	0.73	−140	−235	+.145	+.14
5	0.76	+ 42	−325	+.152	+.15
8	0.75	+ 43	+241	+.244	+.24
11	0.59	+321	+159	+.266	+.27
Parallax star.	0.70	+ 30.7	+ 48.4		

The rotating disk was used with this region, and the diameter given for the parallax star is as it actually appears upon the plates. Each of the first five plates was measured by Miss Ware and the writer, the remaining four by Miss Ware alone.

TABLE 2

REDUCTION FOR μ *Cassiopeiae*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
418	0.070	1.0	+1.009	−200	+11	+″03
421	0.078	0.8	+0.794	−194	+ 6	+.01
426	0.051	0.8	+0.792	−193	−23	−.05
539	0.247	1.0	−0.315	− 95	+ 8	+.02
559	0.281	1.0	−0.707	− 68	− 1	.00
741	0.891	0.9	+0.871	+177	+ 3	+.01
770	0.928	0.5	+0.385	+201	− 5	−.01
778	0.949	0.7	+0.481	+208	+ 3	+.01
886	1.106	0.8	−0.681	+311	− 7	−.02

The normal equations are:

$$\begin{aligned} +5.238\pi - 3.109\mu + 2.629c &= +0.732 \\ +26.960 - 0.184 &= +5.721 \\ +7.500 &= +3.516 \end{aligned}$$

These yield

$$\begin{aligned} c &= +0.460 \\ \mu &= +0.2203 = +0''.586 \\ \pi &= +0.0393 = \mathbf{+0''.105 \pm 0''.010} \end{aligned}$$

Probable error corresponding to unit weight, $\pm 0.0073 = \pm 0''.019$.

In spite of the small number of plates the parallax has been determined with a small accidental error. The largest residual for any plate is $0''.06$, and all the others are under $0''.03$.

Other reliable determinations of this parallax are:

Peter (heliometer)	$+0''.13$	$\pm 0''.013$
Flint (transit circle)	$+0.07$	.026

Lalande 5761 ($3^h\ 3^m$, $+25°\ 58'$)

This is an 8th-magnitude star with a proper motion of a little less than $1''$ per annum. Ten plates were secured as shown in Table 1.

TABLE 1

PLATES OF *Lalande 5761*

No.	Date	Hour Angle	Observers	Quality of Images	Remarks
81 ...	1903 Aug. 16	$-1^h.7$	S, Su, S	Fair	Images triangular and elongated
99 ...	Sept. 20	-0.1	S, S	Fair	Stars (9) and (20) lacking
203 ...	1904 Jan. 31	$+1.9$	S, Su, S	Fair	Telescope east
209 ...	Feb. 4	$+0.3$	S, S	Good	
437 ...	Aug. 25	-0.7	S, Su, S	Good	
451 ...	Sept. 4	-1.1	S, Su, S	Fair	Images triangular
585 ...	1905 Jan. 29	0.0	S, S, Su	Fair	
763 ...	Sept. 10	-1.2	Su, Su, Su	Fair	
784 ...	Sept. 23	-1.2	Su, Su	Fair	
789 ...	Sept. 24	-1.8	Su, Su	Fair	

COMPARISON STARS

No.	Diameter	X (longitude)	Y (latitude)	Dependence	
				Computed	Adopted
4.....	1.07	−321	−330	+.227	+.225
9.....	0.56	−160	+ 22	+.138	+.14
10.....	0.59	−109	+ 28	+.143	+.14
13.....	0.72	+101	+116	+.145	+.15
14.....	0.68	+145	+ 7	+.185	+.18
20.....	1.23	+344	+157	+.165	+.165
Parallax star.	1.56	− 12.7	− 24.0		

The last three plates were measured by Miss Ware alone, the other eight by both Miss Ware and myself.

TABLE 2

Reductions for *Lalande 5761*

Plate	Solution (ss)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
81..	0.460	0.4	+1.011	−357	+38	+″06
99..	0.398	0.6	+0.806	−322	− 8	−.02
203..	0.368	0.8	−0.972	−189	+28	+.06
209..	0.290	0.8	−0.981	−185	−48	−.11
437..	0.258	1.0	+0.988	+ 18	+ 1	.00
451..	0.242	0.5	+0.936	+ 28	−11	−.02
585..	0.203	0.8	−0.967	+175	+23	+.05
763..	0.068	0.7	+0.894	+399	−21	−.05
784..	0.066	0.5	+0.768	+412	−17	−.03
789..	0.118	0.5	+0.757	+413	+35	+.07

The normal equations are:

$$\begin{aligned} +5.628\pi \;+\; 4.518\mu + 1.395c &= +0.188 \\ +47.595 \;+ 2.286 &= -1.477 \\ +6.600 &= +1.630 \end{aligned}$$

These yield

$$c = +0.261$$
$$\mu = -0.0440 = -0''.117$$
$$\pi = +0.0038 = +0''.010 \pm 0''.020$$

Probable error corresponding to unit weight, $\pm 0.0172 = \pm 0''.046$.

This result agrees well with that of Chase, who derived $-0''.001$, with a probable error of $\pm 0''.033$. From five plates taken by Rambaut at the Radcliffe Observatory, Kapteyn obtains a much larger value, $+0''.085 \pm 0''.022$.

Lalande 7443 ($3^h\ 56^m$, $+35°\ 3'$)

This is a star between the 8th and the 9th magnitude with a proper motion of over $2''$ per annum. Eleven plates were secured as shown in Table 1.

TABLE 1

PLATES OF *Lalande 7443*

No.	Date	Hour Angle	Observers	Quality of Images	Remarks
104	1903 Sept. 22	$-1^h.4$	S, Su, S	Poor	Stars (27) and (28) lacking
201	1904 Jan. 31	−0.3	S, Su, S	Good	
218	Feb. 9	+1.3	S, Su, S	Fair	Telescope east
453	Sept. 4	−0.8	S, Su, S	Fair	Images slightly triangular
464	Sept. 11	−1.0	S, Su, S	Poor	
477	Sept. 25	−0.1	S, S, S	Good	
554	Dec. 15	−0.4	S, Su, S	Good	
562	1905 Jan. 3	−0.5	S, Su, S	Good	
765	Sept. 10	−1.1	Su, Su, Su	Good	Star (28) lacking on first exposure
786	Sept. 23	−1.0	Su, J, Su,	Fair	
791	Sept. 24	−1.0	Su, J, Su	Fair	Third exposure poor

COMPARISON STARS

No.	Diameter	*X* (longitude)	*Y* (latitude)	Dependence	
				Computed	Adopted
10	1.33	−209	−124	+.422	+.417
11*a*	1.21	−252	+188	+.389	+.40
27	0.59	+202	− 25	+.113	+.10
28	0.67	+259	− 39	+.076	+.083
Parallax star.	1.32	−144.0	+ 14.4		

For the first plate, which lacks (27) and (28), two other comparison stars, numbered (5) and (6), were used instead. The last

three plates were measured by Miss Ware alone, the others by the writer as well.

TABLE 2

REDUCTIONS FOR *Lalande 7443*

Plate	Solution (m)	Weight (p)	Parallax Factor (P)	Time in Days (t)	Residual (v)	$\sqrt{p}\cdot v$ in Arc
104 . .	0.072	0.2	+0.911	−320	+ 5	+″01
201 . .	0.224	1.0	−0.902	−189	−10	−.03
218 . .	0.266	0.8	−0.955	−180	+20	+.05
453 . .	0.570	0.8	+1.000	+ 28	−11	−.03
464 . .	0.606	0.5	+0.973	+ 35	+14	+.03
477 . .	0.610	1.0	+0.882	+ 49	− 1	.00
554 . .	0.689	0.9	−0.327	+130	+24	−.06
562 . .	0.747	1.0	−0.614	+149	+10	+.03
765 . .	1.147	0.5	+0.979	+399	+18	+.03
786 . .	1.133	0.7	+0.900	+412	−14	−.03
791 . .	1.160	0.6	+0.892	+413	+12	+.02

The normal equations are:

$$+5.758\pi + 8.784\mu + 1.431c = +2.132$$
$$+42.393 + 6.936 = +10.032$$
$$+8.000 = +5.250$$

These yield

$$c = +0.526$$
$$\mu = +0.1476 = +0''.393$$
$$\pi = +0.0145 = +0''.039 \pm 0''.013$$

Probable error corresponding to unit weight, $\pm 0.0095 = \pm 0''.025$.

The parallax of this star has recently been determined by Chase and Russell. By means of the heliometer the former gets $+0''.04 \pm 0''.040$; and from photographic plates Russell obtains $-0''.011 \pm 0''.006$.

c Persei ($4^h\ 1^m$, $+47°\ 27'$)

A number of helium stars that were under observation for radial velocity with the Bruce spectograph of the Yerkes observatory, were put upon the observing program in order to ascertain by direct observation whether stars of this type are as distant as their small proper motions would imply. The present list contains

four of these stars, of which *c Persei* is the first. The magnitude is 4.0 and the proper motion (according to Boss) 0″.044 per annum. The parallax rests upon the eight plates described in Table 1. The rotating disk was used to reduce the light of the parallax star.

TABLE 1

PLATES OF *c Persei*

No.	Date	Hour Angle	Observers	Quality of Images	Remarks
517 ...	1904 Oct. 30	−0^{h}2	S, Su, S	Good	Second exposure poor
524 ...	Nov. 17	−0.9	S, Su, S	Poor	Images triangular
583 ...	1905 Jan. 22	−0.6	S, Su, S	Fair	
586 ...	Jan. 29	−0.4	S, Su, S	Fair	First exposure good
787 ...	Sept. 23	−0.6	Su, J, Su	Fair	Second exposure poor
799 ...	Oct. 3	−0.3	Su, J, Su	Fair	
826 ...	Oct. 10	−0.4	Su, J, Su	Fair	
901 ...	1906 Jan. 28	−0.5	Su, J, Su	Fair	

COMPARISON STARS

No.	DIAMETER	*X* (longitude)	*Y* (latitude)	DEPENDENCE	
				Computed	Adopted
1	0.73	−124	−329	+.211	+.20
2	0.56	−300	− 92	+.398	+.40
4	0.69	+288	+ 95	+.110	+.125
5	1.00	+136	+326	+.281	+.275
Parallax star .	0.78	− 74	− 3		

TABLE 2

REDUCTIONS FOR *c Persei*

Plate	Solution (*m*)	Weight (*p*)	Parallax Factor (*P*)	Time in Days (*t*)	Residual (*v*)	$\sqrt{p}\cdot v$ in Arc
517 ..	0.042	0.9	+0.508	−216	− 1	″.00
524 ..	0.058	0.5	+0.217	−198	+ 8	+.01
583 ..	0.026	0.8	−0.799	−132	−12	−.03
586 ..	0.045	0.9	−0.864	−125	+ 4	+.01
787 ..	0.044	0.6	+0.927	+112	− 5	−.01
799 ..	0.050	0.7	+0.845	+122	− 1	.00
826 ..	0.053	0.7	+0.774	+129	+ 1	.00
901 ..	0.055	0.7	−0.854	+239	+ 4	+.01

There is another good comparison star, numbered (3), at $X = +64$, $Y = -290$; but the dependence comes out small ($+.053$) and this star was accordingly not used. Each of the first four plates was measured by both Miss Ware and the writer, the other four by Miss Ware alone.

The normal equations are:

$$\begin{aligned} +3.384\pi + 1.229\mu + 0.240c &= +0.024 \\ +15.898 - 1.013 &= -0.005 \\ +5.800 &= +0.264 \end{aligned}$$

These yield

$$\begin{aligned} c &= +0.046 \\ \mu &= +0.0024 = +0''.006 \\ \pi &= +0.0031 = +0''.008 \pm 0''.009 \end{aligned}$$

Probable error corresponding to unit weight, $\pm 0.0060 = \pm 0''.016$.

No other determination of this parallax has been published.

ALLEGHENY OBSERVATORY
February 1911

[*To be continued*]

PLATE IX

THE JANUARY COMET OF 1910

Stockholm, January 28, 1910, at G.M.T. $5^h\ 10^m$. Exposure 33^m. Enlargement fourfold. Scale: 1 cm = 1°25

Minor Contributions and Notes

THE JANUARY COMET, 1910 *a*

The accompanying reproduction, Plate IX, of a photograph of the remarkable January comet of 1910 is from a negative made on January 28, 1910, at the Stockholm Observatory with a Voigtländer "Dynar" objective. A reproduction of this negative was first given in *Astronomische Nachrichten*, No. 4433 (**185**, 261, 1910). The scale of the picture is 1 cm = 1°.25.

In addition to the principal tail, there issues from the head of the comet a secondary tail 2° long. The principal tail is slightly curved and extends to a length of 18°, passing between θ and ϵ *Pegasi*. At its extremity the tail is bifurcated. The head forms a very slender pencil. At the time of this exposure the head of the comet was very close to the equator.

KARL BOHLIN

STOCKHOLM OBSERVATORY
December 28, 1910

Reviews

Geodäsie, eine Anleitung zu geodätischen Messungen für Anfänger, mit Grundzügen der Hydrometrie und der directen (astronomischen) Zeit- und Ortsbestimmung. Von H. Hohenner. Leipzig und Berlin: B. G. Teubner, 1910. 8vo, pp. 347, with 216 figures. Bound, M. 12.

This is primarily a textbook for engineering students, written by a Doctor of Engineering, not a Doctor of Philosophy; it should therefore be a "practical" book, free from the defects that always abound in textbooks if the authors have formed the bad habit of making researches in science—researches intended to widen the bounds of human knowledge.

We are often told that the americanization of Germany is about to be completed. Doubtless there, as well as here, the demand made by the engineering student upon his school is that he be transformed, with a minimum of trouble to himself, and in a minimum of time, into a money-earning machine. He has an avid desire to acquire saleable knowledge and a persistent disinclination for "mere theory." Let the force of gravitation be what it will: he desires to be lectured on the horse-power required to overcome that force in the case of a 50-passenger 40-story express elevator; and he prefers to have the lectures presented in the form adopted in the printed documents distributed by elevator manufacturers, and which they are accustomed to call their "literature."

But German thoroughness dies hard. If we are to credit the preface, this book contains only an extract from the author's lectures at the technical schools of Munich, Stuttgart, and Braunschweig: if surveying students there receive instruction in the entire contents of the volume, they certainly have the benefit of a very thorough course. Especially noteworthy is the constant use made of the method of least squares. A brief explanation of it is given on pp. 8–11; later, on p. 143, a very complete treatment begins; and problems are at all times adjusted in strict accord with rigorous principles.

The famous triangulation between Göschenen and Airolo (the two ends of the St. Gothard tunnel) is given as a numerical example on p. 213. This was perhaps the only case in which extremely precise geodetic

methods have been found essential in ordinary railroad engineering practice until the construction of the Hudson River tunnel was undertaken at New York.

There are valuable chapters on trigonometric and barometric leveling, as well as current measurement in hydrographic work; it is to be regretted that photographic surveying has been omitted. The book should certainly receive attention from American teachers of civil engineering.

H. J.

Boletin Mensual del Observatorio del Ebro. Vol. I, No. 1. Enero de 1910.

We welcome the appearance of this initial number of what promises to be an interesting and valuable series of bulletins.

The object of the Observatory del Ebro[1] is to study the relation between solar activity and the magnetic and electric phenomena of the earth. To this end three lines of research are being pursued, viz., astrophysics, meteorology, and geophysics. The first includes the study of sun-spots and flocculi; the second, in addition to the ordinary meteorological observations, includes investigations in atmospheric electricity, the ionization of the air, atmospheric potential, etc.; the last embraces terrestrial magnetism, earth currents, and seismology.

The text of the bulletin is given in Spanish and French in parallel columns. The observations for the month are presented first in tabular form, then graphically. The latter is exceedingly interesting and instructive. All the curves are placed on the same page with the times of observation as abscissas. A comparison of the simultaneous variations of the twenty-four different phenomena is thus rendered easy.

FREDERICK SLOCUM

Newcomb-Engelmanns Populäre Astronomie. Vierte Auflage. Edited by P. KEMPF. Leipzig: Wilhelm Engelmann, 1911. Large 8vo, pp. xvi+772, with 213 illustrations in the text and on 21 plates. M. 14; bound, M. 15.60.

The second and third German editions of this work were edited by the late H. C. Vogel, both on account of his regard for his deceased friend R. Engelmann, translator and editor of the first edition, and on

[1] Situated at Roquetas, Tortosa, Spain; connected with the Colegio Máximo de la Compañia de Jesús.

account of his high appreciation of Newcomb's book. It was a natural desire of the publishers that the fourth edition also should be edited at the Potsdam Observatory, and the three astronomers who were associated with Vogel in preparing the third edition, Messrs. Kempf, Eberhard, and Ludendorff, have likewise participated in the latest edition, as has also Professor Schwarzschild.

It is a fine testimonial to the appreciation of the German-reading public for a solid and comprehensive work on a special science that a new edition should be called for within five years. We say "German-reading" instead of German, because of our conviction that a large call for the work has come from other European countries. The book has never been, nor was it intended to be, popular in the sense of giving the reader a pleasant entertainment. In Newcomb's own words in the preface of the original edition in English:

> The present work is not designed either to instruct the professional investigator or to train the special student of astronomy. Its main object is to present the general reading public with a condensed view of the history, methods, and results of astronomical research, especially in those fields which are of most popular and philosophic interest at the present day, couched in such language as to be intelligible without mathematical study.

In its present form the work is of decidedly composite origin: many eminent authorities have contributed to one or another of the German editions, either in special statements of their views on particular points, or in suggestions to the editor after a careful reading of an earlier edition with a view to revision. Among them may be mentioned Young, Dunér, Küstner, Seeliger, Kapteyn, Kobold, besides the gentlemen named above as editors. Newcomb's own views, as expressed in some of his last popular books in English, are also quoted under some topics. Coming from such sources the book ought to be a good one, and it is undoubtedly the best of its kind in any language.

The principal changes from the third German edition have been these: the section on the determination of orbits (*Bahnbestimmung*) has been rewritten by Schwarzschild; the sections on stellar parallaxes and stellar motions have been revised by Ludendorff; several sections on the sun, by Kempf and Ludendorff; those on the physical constitution of the stars, and on "new stars," by Eberhard; on variable stars, by Kempf; and some sections on the structure of the universe and cosmogony, by Schwarzschild. Many new illustrations have been added, including nine plates.

In accordance with the purpose of the book, no references are given

to the original papers upon which statements are based. This is a relief to the general reader, as such references only disturb the continuity of his thought. They are also unnecessary for the teacher, to whom we especially recommend the book, as he will find in it authoritative opinions on all points of interest, both new and old, in the whole range of astronomy. The many statistical tables, all revised to represent the latest information, are also exceedingly valuable for reference. We wish that an equally good, and up-to-date, edition in English of this standard work could be prepared for those who do not easily read German.

F.

NOTICE

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention is given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

Articles written in any language may be accepted for publication, but unless a wish to the contrary is expressed by the author, they usually will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right unless the author requests that the reverse procedure be followed.

Accuracy in the proof is gained by having manuscripts typewritten, provided the author carefully examines the sheets and eliminates any errors introduced by the stenographer. It is suggested that the author should retain a carbon or tissue copy of the manuscript, as it is generally necessary to keep the original manuscript at the editorial office until the article is printed.

All drawings should be carefully made with India ink on stiff paper, usually each on a separate sheet, on about double the scale of the engraving desired. Lettering of diagrams will be done in type around the margins of the cut where feasible. Otherwise printed letters should be put in lightly with pencil, to be later impressed with type at the editorial office, or should be pasted on the drawing where required.

Where an unusual number of illustrations may be required for an article, special arrangements are made whereby the expense is shared by the author or by the institution he represents.

Authors will please carefully follow the style of this JOURNAL in regard to footnotes and references to journals and society publications.

Authors are particularly requested to employ uniformly the metric units of length and mass; the English equivalents may be added if desired.

If a request is sent *with the manuscript*, one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

The editors do not hold themselves responsible for opinions expressed by contributors.

The ASTROPHYSICAL JOURNAL is published monthly except in February and August. The annual subscription price is $5.00; postage on foreign subscriptions 62 cents additional. Business communications should be addressed to *The University of Chicago Press, Chicago, Ill.*

All papers for publication and correspondence relating to contributions should be addressed to *Editors of the* ASTROPHYSICAL JOURNAL, *Yerkes Observatory, Williams Bay, Wisconsin, U.S.A.*